DEPARTMENT OF GEOGRAPHY

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THE PREDICTION OF ICE FORMATION ON MOTORWAYS IN BRITAIN

by

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ABSTRACT

Each winter, Britain spends up to £120 million spreading approximately 2 million tonnes of rock salt on our roads to keep them free of ice and snow. This thesis shows that it would be possible to significantly reduce the amount of salt spread, by improving the accuracy of the Road Danger Warnings issued to Highway Authorities. Each day in winter, the maintenance engineer receives a Road Danger Warning from his local weather centre. Unfortunately these Warnings are not very accurate because they are based on forecasts of minimum air temperature alone, rather than using road surface temperatures. During the winter of 1982/83, of 102 Road Danger Warnings issued to Hereford and Worcester County Council, only 32 were correct in predicting icy conditions on the M5 motorway.

This thesis presents a computer model to predict ice formation on roads up to 24 hours ahead. During the winter of 1978/79 instruments were installed in the M4 motorway to measure road surface temperature and wetness. The computer model has been tested retrospectively for 30 nights when the road surface temperature fell below $5^{\circ}C$. The predicted minimum road surface temperature has a root mean square error of $0.9^{\circ}C$. During the winters of 1982/83 and 1983/84, the model was tested in 'real time' against road surface temperatures measured automatically on the M5 and M6 motorways, giving a root mean square error of $1.5^{\circ}C$ for 80 nights during 1982/83, and $1.3^{\circ}C$ for 120 nights during 1983/84.

The form of the issued Road Danger Warnings has been changed from a simple sentence issued over the telephone or using telex, to a graph of predicted road surface temperature and wetness. An optimistic and a pessimistic graph is issued to give the maintenance engineer an idea of the certainty of the forecast.

The thesis proposes a national network of automatic road surface monitoring sites. Each site would be linked to microcomputers in local weather centres, which would then run the prediction model and issue Road Danger Warnings accordingly. The information could then be sent to maintenance engineers using Prestel.

ACKNOWLEDGEMENTS

My involvement with the prediction of road surface temperatures started back in 1970 when I worked as a vacation student at the Meteorological Office in Bracknell. I was given a project concerning the development of more accurate Road Danger Warnings. That this project was given to a student sums up the rather dismissive approach of the Meteorological Office to winter maintenance over the years. Hopefully this attitude has now changed, but I am grateful to them for giving me the idea!

This thesis has been undertaken on a part time basis throughout; I registered in 1976. The subsequent 8 years have not been slow to pass, however this is a convenient time for the research to be presented, as the ideas developed in this thesis are now being put into operation.

Without the research grants, amounting to more than £150,000, from the Transport and Road Research Laboratory the research would have remained theoretical. I am indebted to John Porter and especially Brian Parmenter for their unflagging support within the Department of Transport.

I must also thank the Departments of Geography at University College London, and at Birmingham University for providing me with every facility; especially Professor Eric Brown for agreeing to supervise me. Other colleagues who have provided help and encouragement are Len Wood, Robert Blackmore, Peter Roe, Ant Beresford, Gerry Sugrue and especially Robert Osborne who has worked beyond the cause of duty, for instance producing Road Danger Warnings on Christmas day! Of course the Meteorological Services Unit is open every day of the year, and I must thank John Kings, Jim Hales and Capt. Wittridge for their forecasting experience.

During the course of the research I have made many friends among the County Councils and abroad. I would like to thank Adrian Golland, David Wood and especially Mark Ponting who has soon put me straight if any of my ideas have been impractical. I am also indebted to Auli Keskinen of the Finnish Meteorological Office for her guidance and enthusiasm.

Finally I would like to thank my parents for their constant support and interest; Jane for typing the thesis; Cirrus and Portia for being cats; and Siân for proof-reading, love and support.

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CHAPTER 1 INTRODUCTION TO WINTER MAINTENANCE

1.1 Introduction

Each winter in Britain, local and county authorities spend approximately £120 million to keep our roads free from ice and snow. Are the British public getting value for money? Are our roads as safe as they can be during our uncertain winter weather? The answers to such seemingly simple questions are beset with "don't knows" and uncertainty. A recent 'Rayner Scrutiny' (Rayner 1981 discussed in detail in Chapter 2) failed to identify any real savings that might be made to the £11 million share that we spend on our major trunk roads and motorways.

This thesis examines both British and International experiences with regard to reducing the costs of winter maintenance. The central theme of the work is to present a new method of producing 'Road Danger Warnings' that bridges the gap that has developed in recent years between the maintenance engineers and the Meteorological Office. In the sixties and early seventies when rock salt became established as the cheapest way for maintenance authorities to treat their roads, there was a close relationship between the number of Road Danger Warnings issued and the number of times roads were salted. In the late seventies however, cutbacks in public expenditure meant that the maintenance engineer had to minimise his proposed spending and attempt to reduce the number of saltings. Most authorities now restrict salting to priority routes, but they also take less notice of the Road Danger Warnings issued by the local Weather Centres. These warnings are based on minimum air temperature forecasts, and because until very recently, no one had measured road temperatures, they are largely unverifiable.

During the winter of 1982/83 Hereford and Worcester County Council received 102 Road Danger Warnings for their stretch of the M5 motorway. They only salted on 39 nights which meant that the maintenance engineers had to use other sources of information and experience that were more important than the Road Danger Warnings. What other factors do the maintenance engineers take into account? How can Road Danger Warnings be improved? In order to attempt to answer these questions it is important to understand the sources of error that are inherent in current winter maintenance practices. These are outlined in Figure 1.1 and discussed in detail in Thornes , Wood and Blackmore (1977).

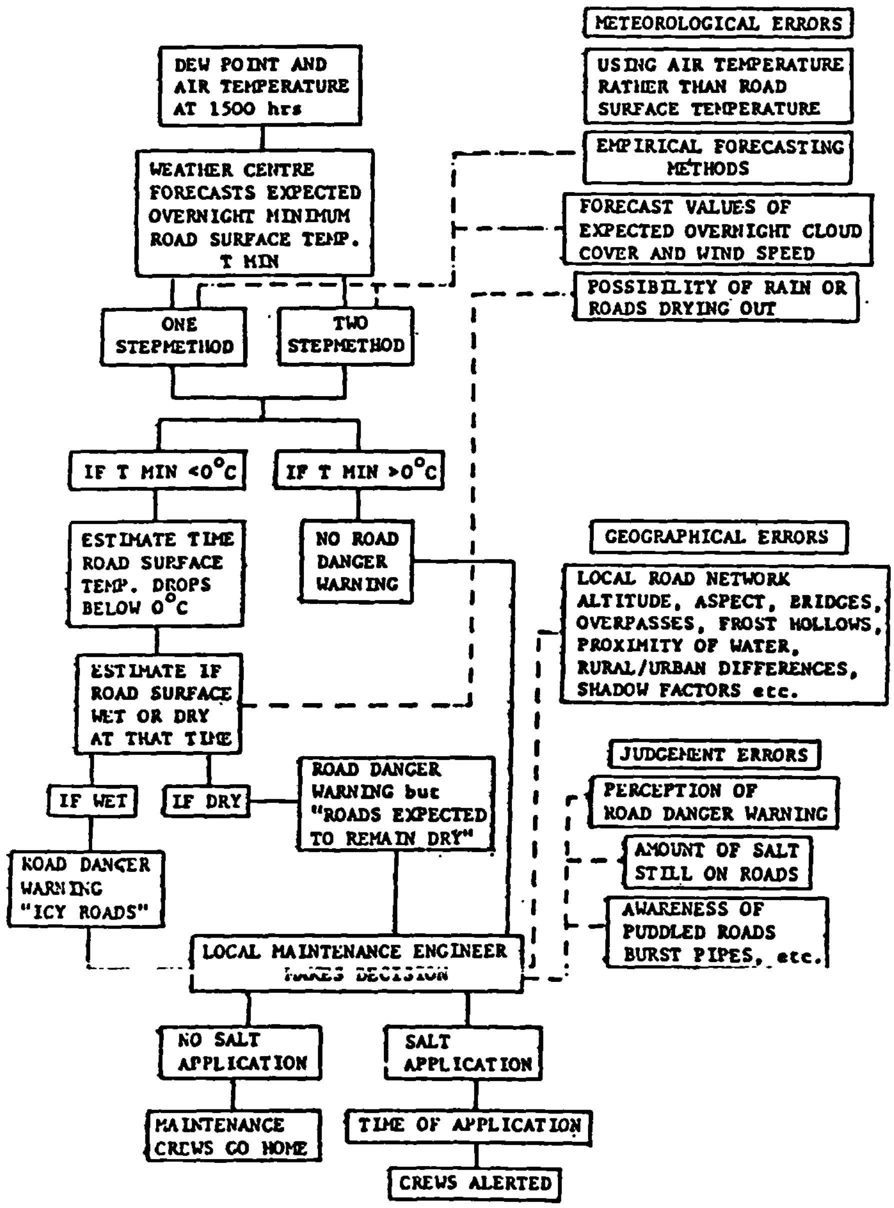
Road Danger Warnings are the common denominator of current winter maintenance practices, in that all authorities receive warnings. An improvement in accuracy is urgently needed to restore the engineers' faith in meteorological forecasts. More accurate warnings will then lead to a reduction in the amount of rock salt spread, and also a reduction in the number of accidents on icy roads.

There are many other factors involved in winter maintenance apart from Road Danger Warnings such as the skid resistance of ice and of a salted road; the ice prevention and melting properties of rock salt; the corrosion caused by rock salt to vehicles and road structures; the problems of storing and spreading rock salt; the use of other de-icing agents or methods; the number of accidents that would have happened if rock salt had not been spread; the design of salt spreading vehicles; the role of the salting vehicle's driver and standby payment. This list is far from complete, and it can quickly be summized that few of these topics are at present within the normal spheres of understanding of the meteorologist or the geographer, or for that matter the maintenance engineer.

These topics will not be discussed in detail in this thesis, but it is important to realise the breadth of understanding required by a maintenance engineer, and by the atmospheric manager, a role defined by Thornes (1978) based on the observations of Terjung (1976).

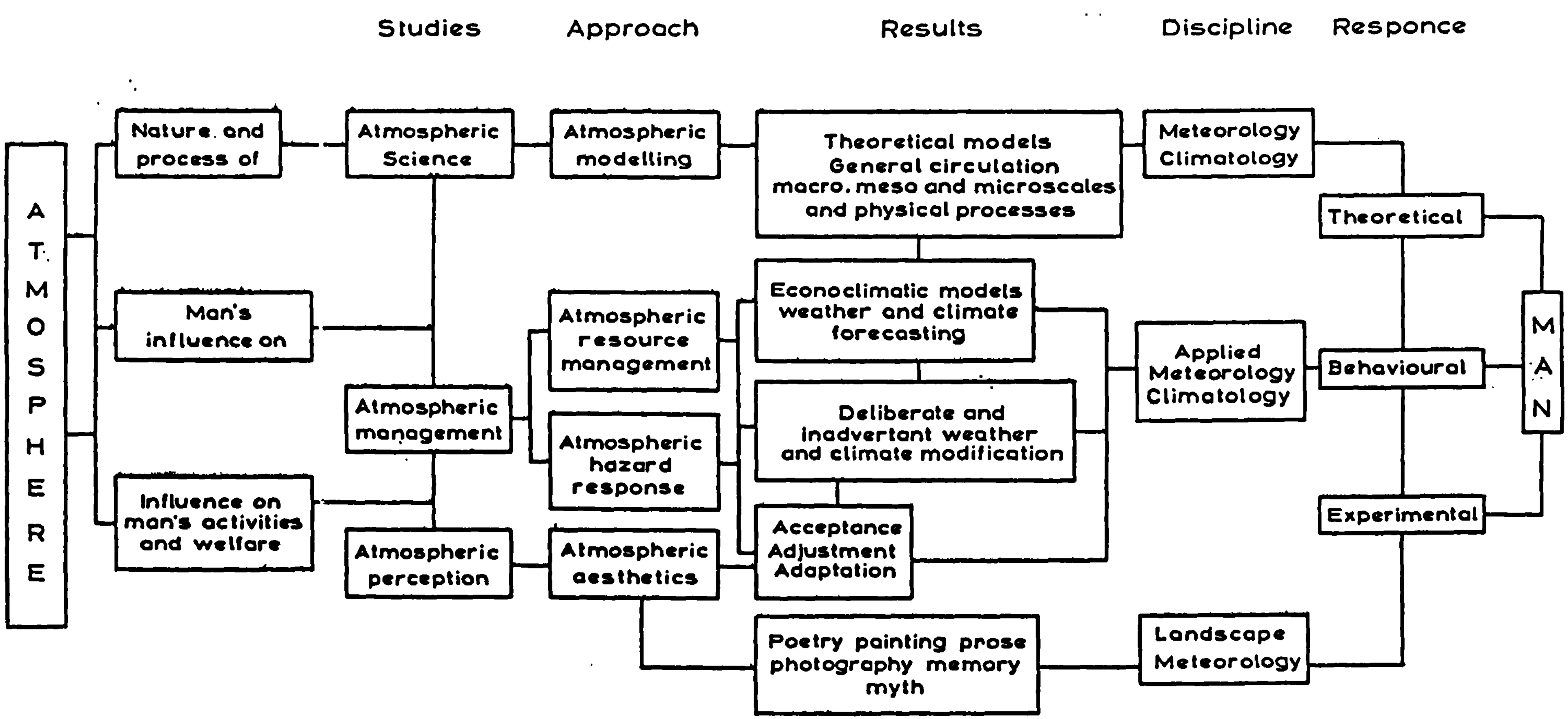
FIGURE 1.1

THE POSSIBLE SOURCES OF ERROR IN THE FORECAST AND TREATMENT OF ICY ROADS.



1.2 Atmospheric Management

The dialectic between man and the atmosphere is expressed in Figure 1.2 a full discussion of which is given by the author elsewhere (Thornes 1978, 1983). Meteorology has patently ignored socio-economic approaches to the atmosphere prefering to concentrate on how the atmosphere works, rather than on the links between the atmosphere and man. This is likely to continue as long as meteorology regards itself as a "physical science", but there are hopeful signs that meteorologists are beginning to realise that if the general public (or non-meteorologists) are to derive maximum benefit from atmospheric information, then the meteorologists will have to go out into the real world and talk to the consumers. Obviously in Britain there is a considerable everyday dialogue between the Meteorological Office and the general public, in the form of weather forecasts on television and radio, and in the newspapers. However the weather forecasters have left it at that. They assume that "Jo Public" understands what a cold front means in terms of weather, and that he also automatically understands such phrases as 'temperatures will be average for the time of year'. However the vast majority of the general public do not understand such terms and a maintenance engineer has no training in meteorology. I have yet to find a maintenance engineer who can distinguish between the weather conditions that lead to the formation of snow as opposed to ice or frost. The Road Danger Warning is a classic case of non involvement by the meteorologist. Instead ot advising whether or not in their opinion the roads should be salted, they escape responsibility stating for instance that 'road surface temperatures may fall below zero'. The general public, and indeed maintenance engineers, do not understand enough about meteorology to interpret the probability of ice formation in that statement. The



A simple model of approaches to atmospheric studies

FIGURE 1.2

Meteorological Office is interested in revenue and protecting its legal responsibilities, and does not see its role as preventing accidents on roads. Obviously the problem is more complicated than just getting the meteorologists to talk to their potential customers. Either one has to train the general public to understand more meteorology, or one has to train the meteorologists to understand more about management, and how decisions are made in the case of winter maintenance. This is why the term atmospheric management has been coined. To take the emphasis away from a study of meteorology or climatology for its own sake, and to replace it with an attitude that starts with a management problem and then seeks a solution using weather information when necessary. Atmospheric management suggests a new paradigm for approaches to the atmosphere (Thornes 1981).

There have been several attempts to employ simple economic analysis to decision making problems in atmospheric management. The most common is probably the cost/loss utility ratio suggested by Thompson and Brier (1955). There have been several suggested improvements, such as Murphy (1966) and Shore (1966), but generally this approach has not been particularly useful as far as winter maintenance is concerned, due to the difficulties of putting a value on traffic accidents that would have occured had the roads not been salted. In 1981 the average cost of road accidents according to The Department of Transport (1982) were:

Fatal	£149,200
Serious	£ 7,900
Slight	£ 1,080
Damage	£ 460

During 1981 there were 160 fatal, 2867 serious and 7993 slight accidents on British roads when snow or ice was present on the road surface

(Department of Transport 1982). The total cost of these accidents was therefore:

Fatal	= £149,200 * 160	= £23,872.000
Serious	= £ 7,900 * 2867	= £22,649.300
Slight	= £ 1,080 * 7993	= £ 8,632.440
	Total	= £55,153.740

The cost/loss utility ratio cannot be calculated from these figures because it is not known how many more accidents would have occurred had there been no winter maintenance. For the sake of argument let us suppose that there would be five times as many accidents. The ratio would then be calculated from the following:

C = the cost of protection against icy roads = £120,000,000 per annum

L = the loss suffered if protective measures are not taken and icy roads occur = £55,153,740 * 5 = £276,000,000

C/L = 120,000,000/276,000,000 = 0.43

If P is the probability of an icy road occurring on a given night then the theory states that if P<C/L do not salt; if P>C/L salt; and if P = C/L do either. Thus if the probability of an icy road is greater than 0.43 then salt. The calculation of C, the cost of winter maintenance is relatively easy. However the calculation of L is so difficult that it makes the exercise almost worthless. Even if accurate accident statistics were available for icy roads with no salting, the values assigned to the costs of accidents could be debated at length.

More recent attempts to use economic theory using 'decision analysis' have also failed to overcome this problem but they have produced some interesting results. Howe and Cochrane (1976) when discussing the application of a decision model to urban snow storms concluded that 'perfect forecasts would have the effect of reducing total cost by as much as 50%'. This is in line with the hypothesis that we are spreading twice as much salt as is required in this country, and probably abroad also. Perfect meteorological forecasts, even on a short time scale, are not possible, but the model presented in this thesis is more accurate than current Road Danger Warnings, as will be shown in Chapter 7. A reduction in costs of 25% is a more realistic figure. Other papers relating to decision analysis but not directly related to winter maintenance are those of Winkler et.al. (1983) and Keeney (1982). More research is needed with real world problems to fill the present void between meteorology and economics.

1.3 Atmospheric Hazards

The atmosphere can be regarded as either a hazard or a resource depending upon the point of view of the consumer. To give an obvious example, snow is a hazard to traffic, but a resource as far as the skiing industry is concerned. With snow and ice however there is unlikely to be a clash of interest between different consumers. Indeed skiing resorts rely upon winter maintenance to keep roads open so that skiers can reach the appropriate ski slopes and resorts. In other instances there can be a clash of interest: rainfall is a hazard to the tourist industry in a mountainous area, whereas it is a valuable resource to the water industry. Frost, ice and snow on roads can safely be classified as atmospheric hazards, but they are formed under differing meteorological circumstances. As far as the motorist is concerned snow can be easily seen and therefore it is more likely that the appropriate caution is taken. Ice is often invisible to the motorist in the form of "black ice", when water has frozen on a road surface to give clear ice crystals. The black road can hence be seen through the ice and so the name "black ice". Hoar frost is again a visible phenomena, and does not normally create such a hazard as black ice, unless it is compacted into ice by traffic (Thornes 1973).

Lindqvist and Mattsson (1979, p18) have taken the distinctions between snow, ice and frost as far as it is ever likely to go, in distinguishing between 24 potential situations when slippery roads are generated as shown in Table 1.1.

As far as Sweden is concerned Lindqvist and Mattsson identified 8 of the 24 as being the most common, these are marked with a star (*) in the table. Certainly these eight also cause most of the problems in Britain, although no survey of frequency of occurences has been carried out. This classification is useful in that it shows the breadth of meteorological situations that can lead to slippery roads. It also reminds us that a wet road is slippery too, though not to the extent of an icy road, as shown in Figure 1.3 taken from Thornes (1973). The problems associated with snow as a hazard have been discussed in detail elsewhere in the literature (Rooney J.F. 1973, Hornigold 1970, Perry 1981, Gray and Male et.al. 1981), but the history of winter maintenance in Britain involves both snow and ice, and indeed maintenance engineers rarely distinguish between them. This is unfortunate because the meteorological circumstances leading to snowfall are often very different to those producing ice and frost. Lowndes (1971) showed that most of the substantial snowfalls between 1954 and 1969 in Britain were linked to either a warm front or a warm occlusion from the southwest, or a polar low or trough to a northerly airstream. As will be shown in Chapter 7 the coldest road temperatures are associated with anti-

Table 1.1 Situations Leading to a Slippery Road

A. ICE

a. Coating of ice (glazed frost)
*(1) Water covering which freezes (including water from melted snow)
*(2) Supercooled rainwater
*(3) Rainwater freezing at a cold surface
(4) Supercooled fog-water
(5) Fog-water freezing at a cold surface
*(6) Coating of ice formed from packed snow
(7) Freezing dew

b. Hoar-frost
*(8) Hoar-frost due to radiative cooling
(9) Hoar-frost due to advection
*(10) Hoar-frost during a period with increasing (air) temperature but still a cold road surface

c. Covering of frost of other kind than hoar-frost
(11) Freezing dew
(12) Supercooled fog-water (rime)
(13) Fog-water freezing at a cold surface

d. Naled (icing)
(14) Water supply from the side of the road; freezing on the road

B. SNOW

a. Loose snow
*(15) Direct snowfall
(16) Drifting snow
(17) Supply in other ways

b. Packed snow
*(18) Influence of traffic
(19) Melting - refreezing
(20) Packing in other ways

c. Slush
(21) Influence of traffic
(22) Influence of salt

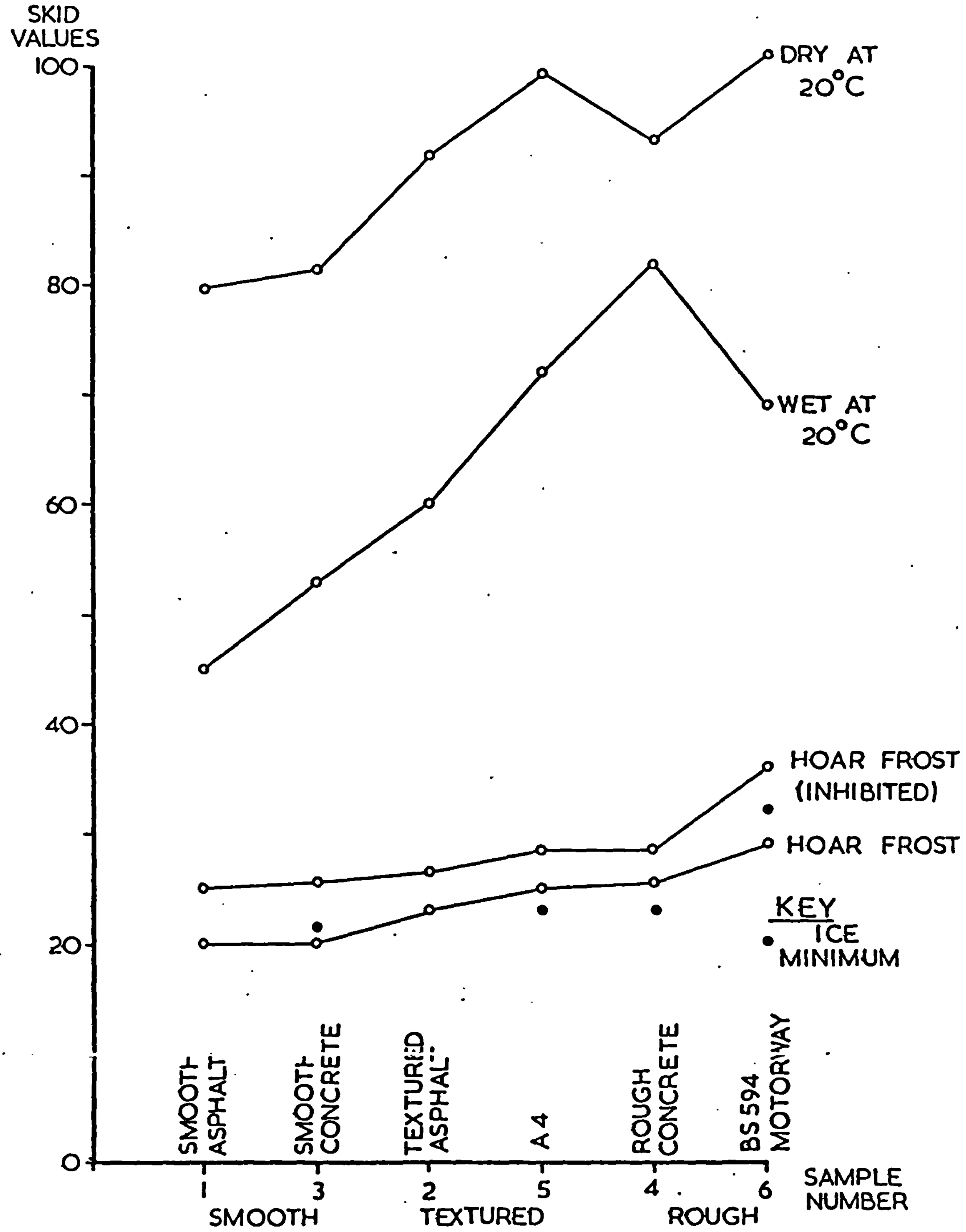
d. Sleet
(23) Melting snow at air temperature > 0°C
(24) Melting snow at air temperature < 0°C

C. WATER

D. HAIL

FIGURE 1.3

COMPARISON OF SKID TEST VALUES FOR DIFFERENT SURFACES AND CONDITIONS

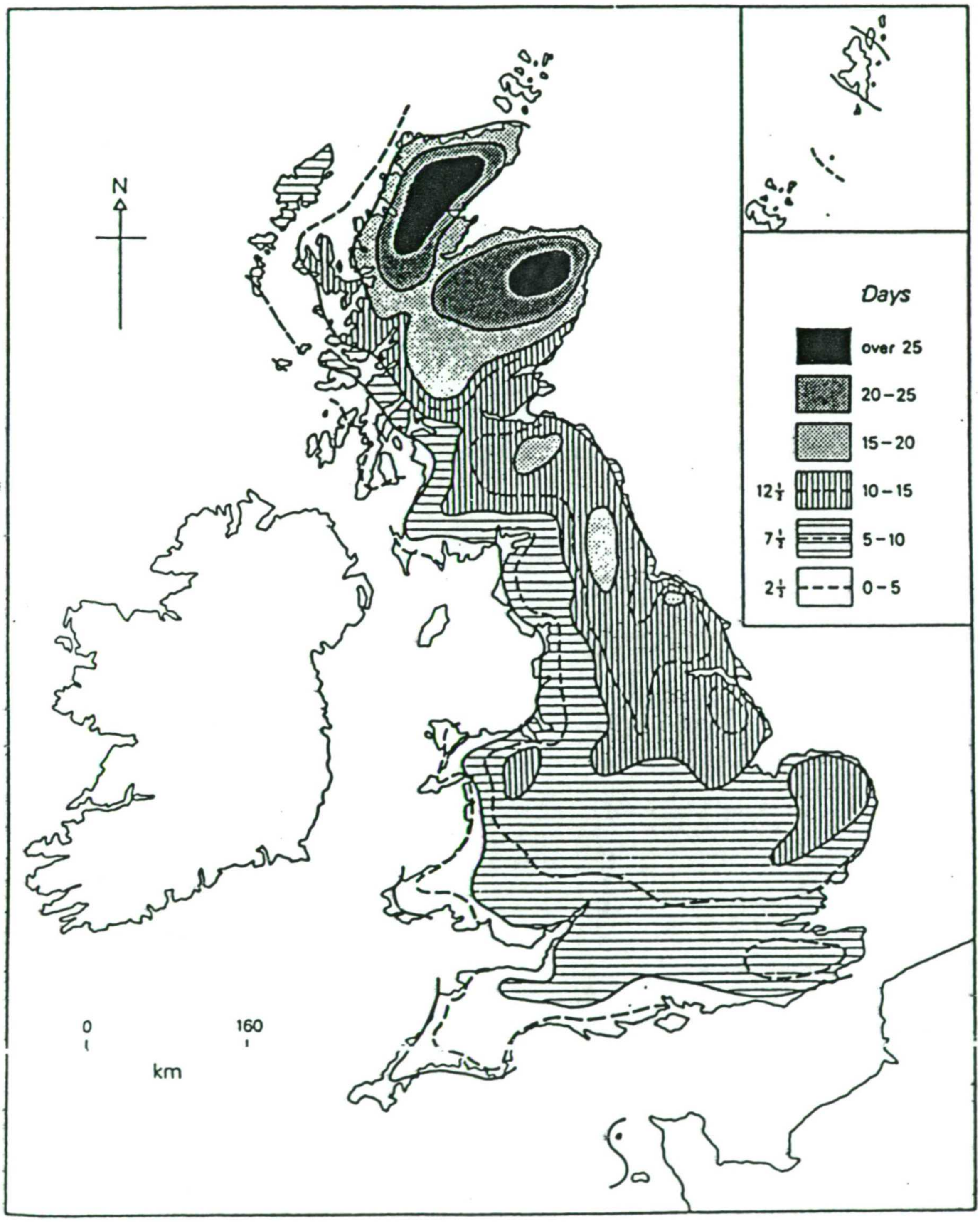


cyclonic conditions, and perhaps the most dangerous road conditions are caused by clearing skies behind cold fronts. Hence the weather conditions associated with ice and snow are often very different. Topography also plays its part in that snow tends to be a greater problem with increasing altitude whereas ice can be a low altitude problem due to cold air pooling. In Britain snow is not a regular annual occurrence, and it is not rare for no snow to accumulate at all during some winters. Figure 1.4 taken from Perry (1981 based on Jackson 1978) shows a marked gradient from southwest to northeast of the number of days with snow lying in a median winter. Figures for a median winter are used because of the variability of such snow day totals from winter to winter. The frequency of ice formation is much more difficult to quantify, but nevertheless is undoubtably much greater than that of snow. During the winter of 1983/84 the motorway surface temperature, as measured on the M5 at Chapman Hill, fell to 0°C or less on 66 nights, of which the road was wet on 34 nights. However ice was not observed to form on more than 2 of the 34 nights due to the salting of the motorways as will be discussed in detail in Chapter 7. Snow was lying at 9 a.m. on only 9 days at Birmingham University, 10 kilometers to the northeast. Hence in Britain a large proportion of the money spent on winter maintenance is for the prevention of icy roads, rather than for the removal of snow. Obviously on some nights the melting of snow during the day can lead to ice formation at night, and so the two cannot be distinguished entirely.

1.4 The Ice/Snow Hazard and Traffic Flow/Accidents

The Highways Act of 1959 (H.M.S.O. 1959) made county and local authorities responsible for keeping their roads free of ice and snow. Section 129 states:

Figure 1.4 Number of days with snow lying in a median winter reduced to sea level. Calculated from 1941–70 means (after Jackson 1978).



'If an obstruction arises in a highway from accumulation of snow or from the falling down of banks on the side of the highway, or from any other cause, the highway authority for the highway shall cause the obstruction to be removed from time to time....'. This rather vague description of the highway authorities responsibilities is not just to reduce the number of traffic accidents that might occur on slippery roads, but also to keep the roads open to traffic. The aim of winter maintenance according to Gloucestershire County Council (Unpublished winter maintenance procedures) is 'To ensure that roads are in such a condition that essential traffic can move with reasonable speed and safety'. The key words are 'essential traffic', 'speed' and 'safety'. Essential traffic presumably means ambulances, fire engines, police cars and buses as far as the authority is concerned, and usually routes involving such traffic are treated first. Speed is often associated with commuting time in large cities, as well as the time it takes for an ambulance or fire engine to reach its destination. With the opening of the motorway network in Britain, and other high speed roads, driving time expectations have become much shorter. Also winter travel time expectations have come to equal those of summer, and much of the National Economy depends upon it for the distribution of goods. Hence time is money as far as travel upon roads is concerned. Safety is concerned with the number of accidents that occur related to ice and snow. Obviously an icy road is more dangerous to drive upon than a wet or dry road, due to the low skid resistance of ice, as shown in Figure 1.3. Codling (1974) relates weather and road accidents in Britain using published statistics for 1969 and 1970 taken from the annual summary of Road Accidents in Great Britain published by the Department of Transport. These statistics are based on police reports filled in, at or about the time of a reported accident. The weather information has to be treated with some caution therefore, as the report may be filled in several hours after an accident. The figures relating to road surface condition have to be treated with even more caution when it comes to the number of icy roads reported in accident statistics. Ice may only be present on a stretch of road for less than an hour, for instance around dawn. By the time the police reach the scene of an accident the road surface condition might well have changed. It must also be borne in mind that ice is very rarely present on main roads due to the excessive amounts of salt that are spread, as will be discussed in the next section. Therefore the accidents which are reported to be related to icy road conditions are taking place on the relatively few nights when salt was not spread. Hence the statistics do not reflect in any way the number of accidents that would occur on icy roads if there was no winter maintenance. Codling (1974) is extremely misleading when he states that in 1973 prices 'It is estimated that the average increase in costs of accidents due to bad weather conditions amounts annually to about £42 million in wet weather, £3 million in snow and ice, £1 million in fog...'(page 220). He is referring to the extra accidents that occur in bad weather over and above the average number of accidents each year. The total for snow and ice is misleading because it does not take into account the number of extra accidents that would have occurred without winter maintenance. Hence it gives a false impression that winter maintenance is not very important. Similarly, Codling underestimates the importance of snow and ice when he states that 'In 1970, only about 4% of all injury accidents occurred on "icy" roads....'(page 221). The proportion of reported injury accidents on "icy" roads has remained more or less constant according to the statistics:

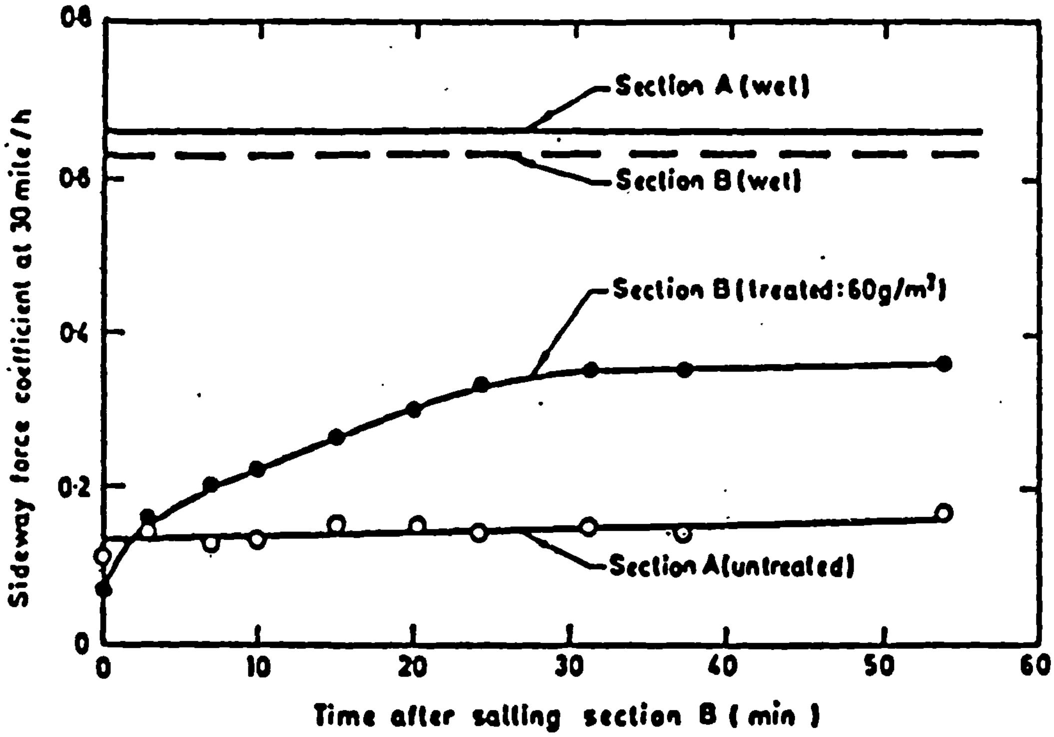
1976	3.2%
1977	2.5%
1978	3.9%
1979	7.1%
1980	3.3%
1981	4.4%

except in 1979 when interestingly the figure was 7.1%, double the average for the other 5 years of 3.5%. The winter of 1978/79 was a cold one, but also there were a number of gritting strikes around the country, due to cut backs in standby payments. Unfortunately it is not possible to separate out the effects of the cold winter and the gritting strikes, however it does suggest that the average would be much higher without winter maintenance. Further research is needed into this aspect of the problem.

1.5 The History of Winter Maintenance in Britain

Before the mid-1950 s winter maintenance was primarily concerned with the spreading of grit on roads to increase the skid resistance of road surfaces covered by ice or snow. Hence the phrase 'gritting' which survives today. The sort of grit used varied according to what was locally available. Waste ash from furnaces was often used, or simply large grained sand. The use of chemicals to melt ice or snow, or to prevent their formation, was first suggested in 1941 by the Road Research Laboratory. The rock salt mine at Winsford in Cheshire has been open since 1844, but production was small until the mid-1950's. An Imperial Chemical Industries (ICI) fact sheet about the mine states that: 'The rapid development of motor transport and high class roads from the 1950's and the need to keep this road traffic moving safely in winter conditions led to a sharply rising demand for ICI Rock Salt Grade 4 for removing ice and snow.'. For an excellent introduction to the properties of rock salt for winter maintenance see Williamson (1969). He also shows that not only is salt corrosive to motor vehicles, and damaging to the environment, it is also slippery. The skid resistance of a salted road is much less than that of a wet road as shown in Figure 1.5. Williamson's answer to the problems of rock salt was to suggest under-road heating. Unfortunately the cost was and is too great. Salt is here to stay. Hay and Young (1972) accepted that salting is inevitable, and presented a far sighted scheme to measure road surface temperatures and wetness to improve Road Danger Warnings. It was through discussions with them that this thesis was started, to provide the forecasting model that would take the observed road surface conditions, and predict how the road surface temperature would change, taking into account the forecast synoptic situation. The aim is therefore to reduce the amount of rock salt spread on our roads.

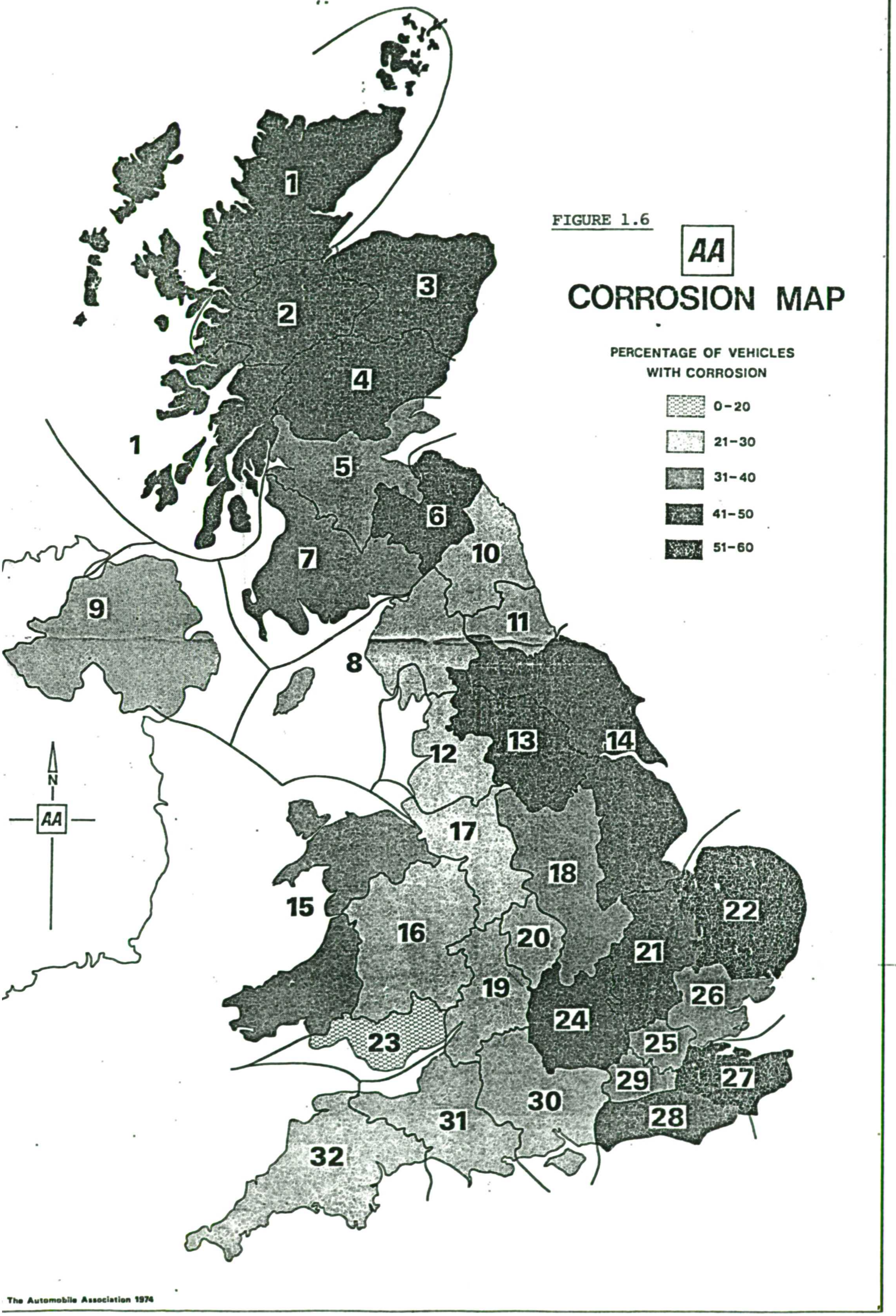
There is a vast literature on the corrosive nature of rock salt, and the subsequent damage to vehicles, road structures, soils and plants. In Thornes and Blackmore (1977) it is shown that the relationship between the amount of rock salt spread and vehicle corrosion is not linear. The Automobile Association (1974) published a corrosion map based on the inspection of second hand cars, as shown in Figure 1.6. It seems that the greater the rainfall the less the corrosion, in that heavy rain washes salt both off the roads and off vehicles. Salt merely speeds up corrosion, it is not a direct cause in itself. Hence reducing the amount of salt spread on our roads will not lead to a linear reduction in vehicle corrosion (see Thornes and Blackmore 1977 for further discussion and references).



Rate of improvement of skidding resistance of icy roads after treatment with salt

FIGURE 1.5 (from Williamson 1969)

FIGURE 1.6


AA
CORROSION MAP
PERCENTAGE OF VEHICLES
WITH CORROSION
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31-40
41-50
51-60
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The Automobile Association 1974

The climate of a country should determine the commitment to winter maintenance in the form of how much plant, and how many maintenance depots are needed. However little international research has been done to compare the total commitment to winter maintenance of different countries. The Raynor Scrutiny carried out in Britain (discussed in detail in Chapter 2) found little relationship between expenditure and climate on a county level.

The weather determines the operational costs of winter maintenance, but does the amount of salt spread reflect the severity of winters in Britain? Table 1.2 shows the average annual order of salt by county from ICI, and Figure 1.7 shows how that annual order is indexed with respect to the number of kilometers of main road in each county. It can be seen that there are several anomalies. West and South Yorkshire for instance use far more salt than one would expect. Generally speaking coastal regions use less salt and central regions away from the warming influence of the sea, use most. There is also a tendency to use more salt in the north and east than in the south. Figure 1.8 shows how the amount of salt spread in Britain has increased from only 50,000 metric tonnes in 1955 to over 2,000,000 metric tonnes in 1979 and 1980. It also shows how production of rock salt has increased to meet demand. The winter severity index developed by Hulme (1982) has been plotted against the salt demand in the following year as show Figure 1.9. The points are only for the years which are after 1966, by which time it can be argued that the use of rock salt had spread into all areas, and hence reflected the severity of the previous winter. The correlation coefficient is -0.85 which is significant for 13 degrees of freeedom at less than the 1% level. This is to be expected

Table 1.2 Estimated demand for rock salt by Counties following a winter of average severity (Source I.C.I.)

England	salt demand tonnes	Km of road	salt/ Km
Avon	8000	4369	1.83
Bedford.	8000	2183	3.67
Berks.	8000	3055	2.62
Bucks.	15000	3345	4.48
Cambridge.	12000	4488	2.67
Cheshire	30000	5237	5.73
Cleveland	15000	2093	7.17
Cornwall	7000	7372	0.95
Cumbria	35000	7274	4.81
Derby.	50000	5335	9.37
Devon	15000	12934	1.16
Dorset	5000	4513	1.11
Durham	30000	3696	8.12
Essex	20000	7091	2.82
Gloucest.	20000	4873	4.10
Gtr. Manch.	40000	7658	5.22
Hampshire	20000	7988	2.50
Here.& Wor.	15000	7180	2.09
Herts.	15000	4195	3.58
Humberside	30000	5467	5.49
Kent	30000	8362	3.59
Lancs.	35000	7147	4.90
Leices.	25000	4904	5.10
Lincs.	30000	8437	3.56
Gtr. London	15000	12806	1.17
Merseyside	15000	4110	3.65
Norfolk	15000	8697	1.72
Northants	15000	3596	4.17
Northumb.	30000	4856	6.18
N. Yorks.	70000	9066	7.72
Notts.	25000	4402	5.68
Oxford.	12000	4079	2.94
Salop	20000	5516	3.63
Somerset	10000	6331	1.58
S. Yorks.	70000	4961	14.11
Stafford.	40000	5865	6.82
Suffolk	7000	6087	1.15
Surrey	7000	4284	1.63
E. Sussex	6000	3469	1.73
W. Sussex	5000	3558	1.41
Tyne & Wear	35000	3883	9.01
Warwick.	25000	3323	7.52
W. Midlands	45000	6350	7.09
W. Yorks.	120000	7756	15.47
Wilts.	15000	4691	3.20
Total England	1120000	257676	4.35

Wales	salt demand tonnes	Km of road	salt/ Km
Clwyd	25000	4119	6.07
Dyfed	20000	8014	2.50
Gwent	15000	3186	4.71
Gwynedd	20000	4509	4.44
Glam. Mid	15000	2544	5.90
South	7000	1589	4.41
West	8000	1647	4.86
Powys	15000	5614	2.67
Total Wales	125000	31222	4.00

Scotland			
Borders	10000	2986	3.35
Central	20000	1956	10.22
Dum.& Gall.	10000	4242	2.36
Fife	15000	2063	7.27
Grampian	20000	7464	2.68
Highland	55000	6982	7.88
Lothian	20000	3250	6.15
Strathcl.	80000	12670	6.31
Tayside	25000	4590	5.45
Total Scotland	255000	49138	5.19
Grand Total	1500000	334304	4.49

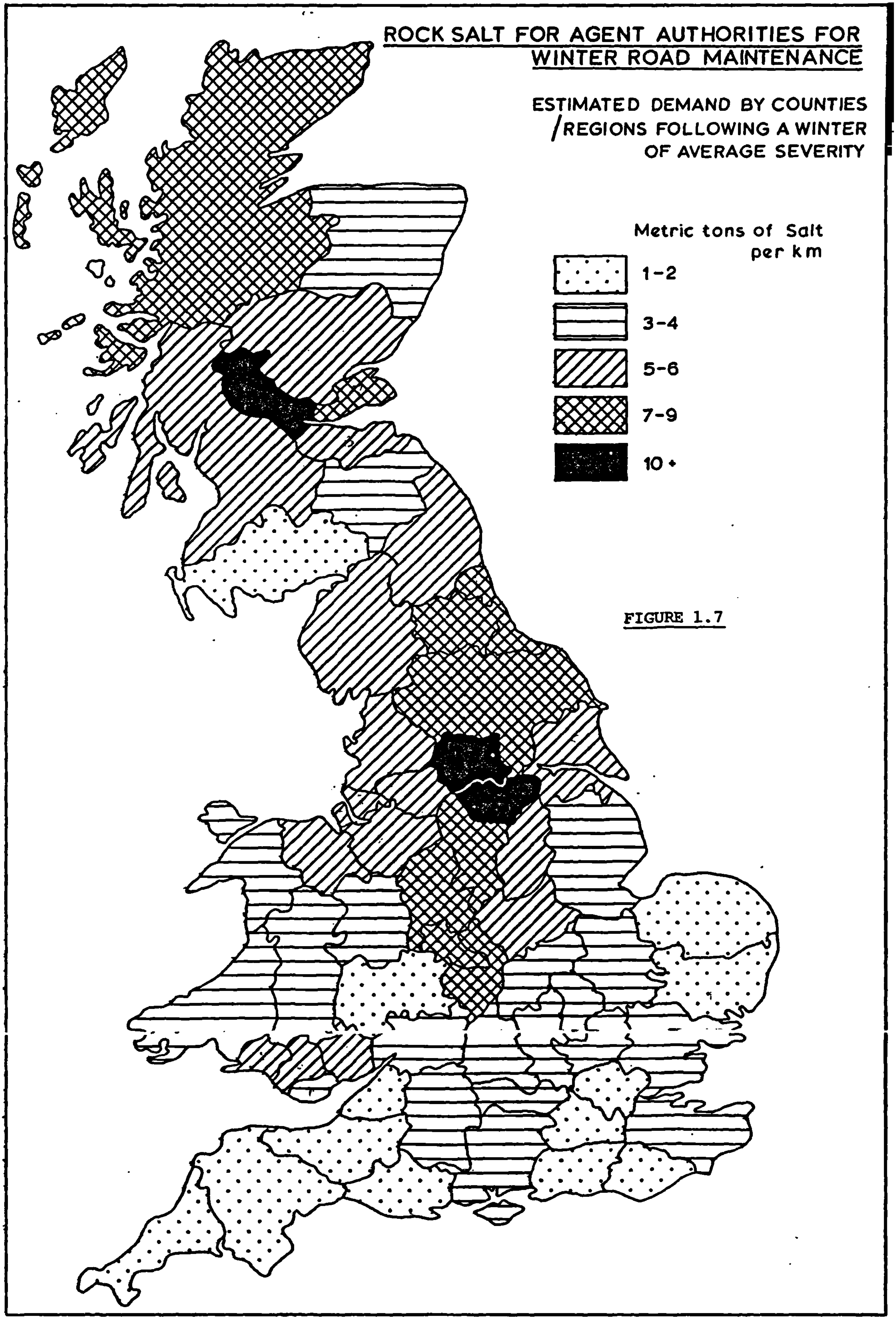
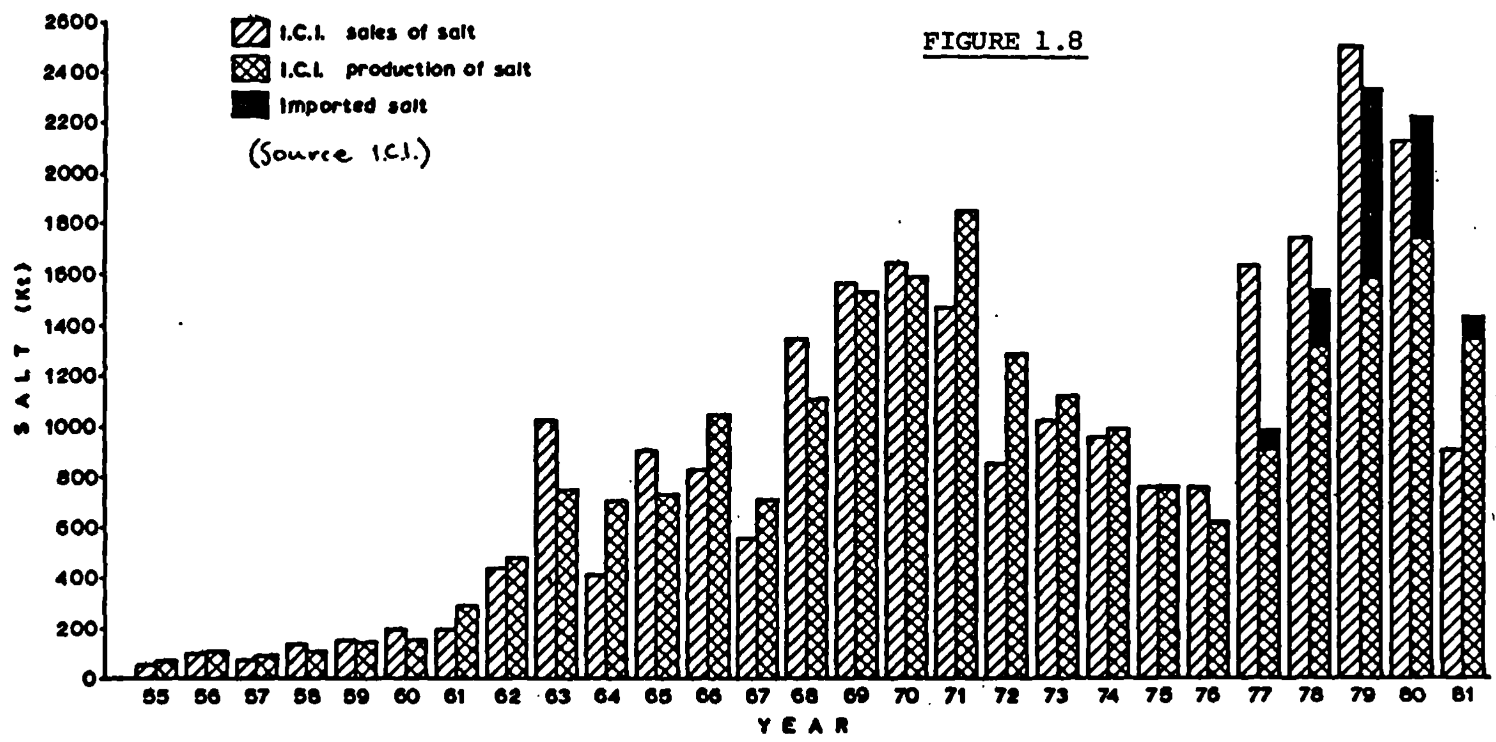

ROCK SALT FOR AGENT AUTHORITIES FOR WINTER ROAD MAINTENANCE
ESTIMATED DEMAND BY COUNTIES /REGIONS FOLLOWING A WINTER OF AVERAGE SEVERITY
Metric tons of Salt per km
1-2
3-4
5-6
7-9
10+

FIGURE 1.7

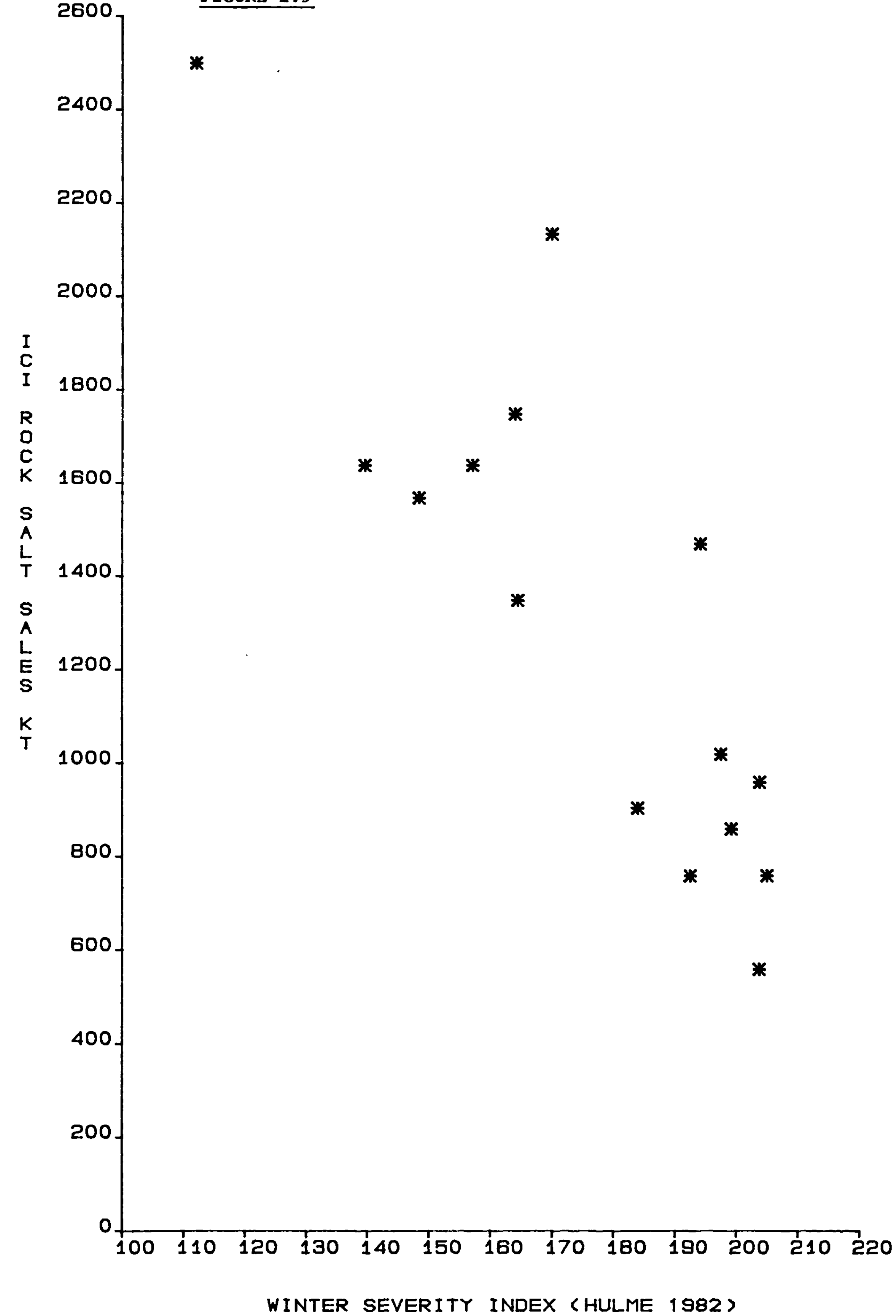
THE SALE AND PRODUCTION OF ROCK SALT 1955 - 1981

FIGURE 1.8



ICI ROCK SALT SALES VERSUS WINTER INDEX

FIGURE 1.9



of course as authorities restock their salt piles after severe winters. ICI claim that in an average winter they sell about 1,500,000 tonnes of salt. Imported salt can take the total sales up to about 2,000,000 tonnes. Using the mean winter index calculated by Hulme to be 178 for the four stations that he used for the years 1930-1981, regression analysis predicts sales of about 1,400,000 which suggests that ICI are optimistic. However if we take the mean for the 1960's and 1970's, which is 171.4 we get a prediction much closer to 1,500,000. Of the decades considered by Hulme the 1960's were the coldest with an index of 165.3, whereas the 1970's were very similar to the average with an index of 177.5. Sales of rock salt probably reached a peak in the late 1970's since when cutbacks in authority spending have meant cutbacks in the spreading of salt. Hence ice and snow are becoming more of a hazard as fewer local roads are being salted to save money, and also because the maintenance engineers are taking bigger risks in deciding whether or not to spread salt. The measurement of road surface temperatures and wetness, together with improved road danger warnings can only help to reduce the impact of the hazard.

The current procedures for the winter maintenance of local roads are left to individual authorities to prescribe. However the maintenance of motorways and trunk roads is controlled by the Department of Transport. They issue a 'Statement of Service and Code of Practice' to all agent authorities as will be discussed in more detail in Chapter 2. The latest isssue is that of 1981 (Department of Transport 1981), which contains several vague generalisations, for instance:

'The decision to salt rests upon local experience and judgement. The general weather forecast should be qualified by factors such as local geographical idiosyncrasies, humidity measurements, wind speeds, and residual salinity observations. If a meteorological warning is not available, precautionary salting should be carried out when falling temperatures reach plus 1°C, provided the prevailing humidity, residual salinity and cloud cover warrant the decision.'

This is too vague to be of any practical use. Nowhere does it state what humidity or temperature measurements should be made, or where, or how to interpret them. Is the temperature of 1°C an air temperature at the depot, or an air temperature near the road, or a road temperature? Clearly there is a complete lack of understanding of the meteorological conditions that lead to ice formation. Similarly the local weather centres that issue Road Danger Warnings know little about road surface conditions. This thesis aims to show that by measuring road surface conditions in real-time, much better Road Danger Warnings can be produced.

1.6 International Research into Winter Maintenance

The research reviewed in this section will be restricted to attempts to improve road danger warnings rather than research into salting practices. European interests have been served by the "EURO-COST 30" programme which has been lookingat electronic traffic aids for major roads since 1976. Theme 8 of this programme is concerned with the development of automatic detection of bad weather conditions, of which ice and snow are a further subset. British involvement has been mainly via the design and testing of various fog detecting instruments (Jeffery et.al. 1981), and the major share of the ice and snow problem has been tackled by Finland. As such the Finnish Meteorological Office are probably the most experienced in the world with regards to winter maintenance. Therefore it is best to look at their research contribution first.

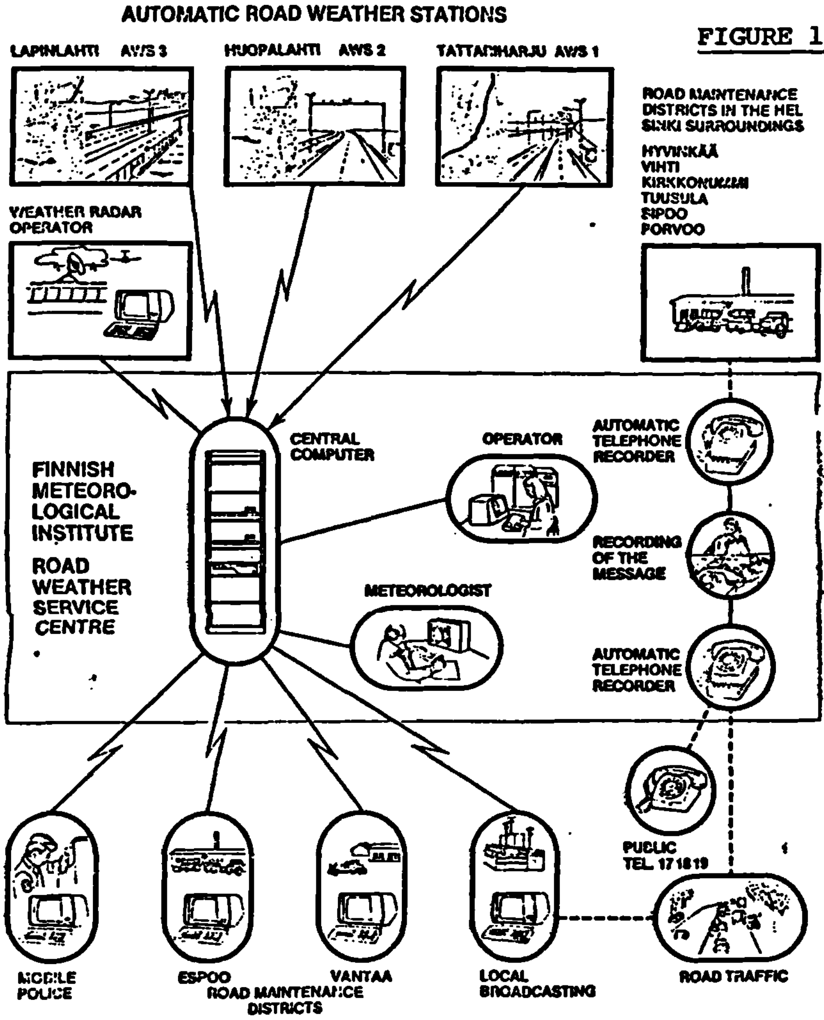
1.6.1 Finland

During March 1983 I visited the Finnish Meteorological Office in Helsinki. The Finns have developed a road surface temperature prediction model which is similar in concept to the model outlined in this thesis (Nysten 1980). The two models have been exchanged and research is now being conducted to compare their performance in real time forecasting. In Finland the climate is such that the road surface temperature is below 0°C for weeks at a time in winter. Hence their need for a road surface temperature model tends to be greatest at the beginning and end of the maintenance season. In Britain we need to forecast the road surface temperature virtually every night in winter due to the fluctuations in temperature above and below zero.

During the winter of 1981/82 an experiment was held in Helsinki when, according to Keskinen (1982) 'two road masters, local radio broadcasting and motor police were provided with special weather services by a real time automatic viewdata transmission system.' Three sites were instrumented on the motorways surrounding Helsinki, and the forecast road surface temperature was issued using the Finnish version of Prestel, as shown in Figure 1.10. This system has been developed as part of the COST-30 programme as outlined in the Theme 8 final report (referenced as Theme '8' 1979), and other reports such as Nysten and Keskinen 1977, Nysten 1980, Kari 1976, Keskinen 1979, and Keskinen 1980. This system is undoubtably the most advanced in Europe, and probably the world. Not only was the experiment a success in terms of the calculated cost/benefit, but also the Ministry of Communications in Finland has already proposed a strategy

Road Weather Service Demonstration In Helsinki

FIGURE 1.10



Demonstration is a part of the road weather service development project established by the Ministry of Communications. Participants in the project are:

MINISTRY OF COMMUNICATIONS
ROADS AND WATERWAYS ADMINISTRATION
FINNISH METEOROLOGICAL INSTITUTE
MOBILE POLICE
FINNISH BROADCASTING COMPANY
CENTRAL ORGANISATION FOR TRAFFIC SAFETY

Demonstration period November 1981 — March 1982

LOCATION OF ROAD WEATHER STATIONS (AWS)

for expanding the present system nationwide; to employ up to 38 new meteorologists by 1989. This scheme is discussed in Chapter 8 when proposed winter maintenance strategies for Britain are discussed.

A further demonstration of the Finnish system is taking place in The Netherlands during 1983/84. Results have not yet been published, but the Finnish road surface temperature model has been adjusted for The Netherlands. This was not a straight forward task as the radiation simulation in the Finnish model is empirically based on Helsinki data. The winter of 1983/84 will reveal the model's success at being 'exported'.

Clearly this thesis has to be read in the light of Finnish research. It is not the intention to compare the models in this thesis as the Finnish model requires considerable modification to run for a British site, due to the radiation problem. A version of the Finnish model is running using the radiation generator presented in this thesis, and is described in an M.Sc. thesis by Britten (1983). The Finns only run their model for up to 6 hours ahead which would be a problem for maintenance engineers in this country, but the model could be extended to give a 24 hour forecast.

1.6.2 Sweden

Research in Sweden is outlined by Lindqvist and Mattsson (1979) and Lindqvist (1979, 1982). They have developed a network of sensors measuring road surface temperatures around Göteborg, and plans to extend the network to Stockholm are already underway. The Swedes do not use a prediction model for road surface temperature, preferring to use the experience of local forecasters. They have carried out extensive trials of 'thermal mapping' however over the last few years, to the extent that they now offer a commercial service, as shown in Figure 1.11. Thermal mapping will not be discussed in detail in this thesis, but it has a very important role to play in the siting of sensors as discussed in Chapter 7, and in Sugrue, Thornes and Osborne (1983) and in Sugrue (1983).

1.6.3 Other European Countries

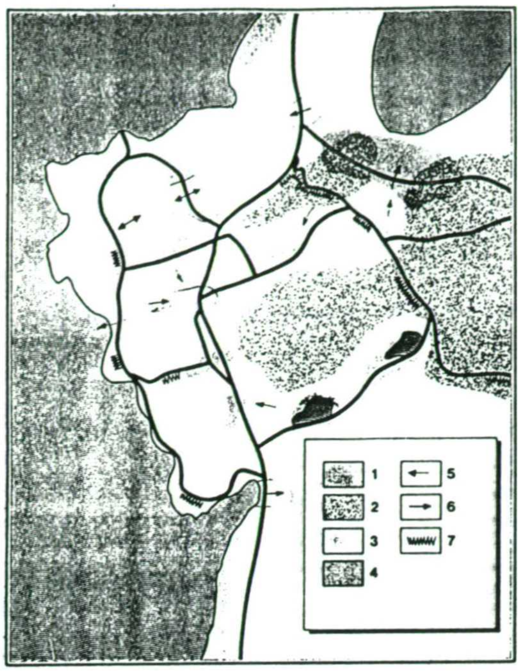
Virtually every country in Europe has carried out some research into winter maintenance, but no international bibliography has yet appeared. Therefore just the relevant publications that have been produced in recent years will be listed. Holland has been quite active, and is staging the current demonstration for the COST-30 Theme-8 programme. Elsenarr and Hoekstra (1975) have looked at the effectiveness of Dutch rock salt, and Ten Cate (1979) described the development of the use of sensors in Holland.

Helsen (1973) describes the environmental problems of the use of de-icing salts in Belgium, and Belfanti (1977) outlines winter maintenance practices in Italy. Dultinger (1976) from Austria looks at the whole problem of winter maintenance, and Auzilleau and Desfresnes (1977) describe an experiment to pass on Road Danger Warnings to motorists, via the radio in France.

It seems that no other research into the prediction of road surface temperatures has been carried out apart from in Finland and Sweden.

1.6.4 North America

Sutherland (1980) presents a simple heat balance model to forecast surface temperatures which has been used operationally in Florida, North America.



ROAD CLIMATOLOGY

Information about the special climatic conditions adjacent to roads is important in the design of new roads and for efficient road maintenance, particularly during the winter. For example, flows and accumulations of cold air increase the risk for local frost under certain weather conditions. Elevated sections may be more exposed under other circumstances. Lakes, marshes and woods cause special local climatic conditions. The design of the road also affects the temperature of the road surface. Bridges are well known for being slippery when there is frost.

A method of preparing special road-climate maps has been developed. The content of maps made to date has been dictated principally by the risk of local icy conditions, but attention has also been paid to the risks of snow accumulations and reduced visibility (snow and fog).

Advice can be given on all the special climatic problems associated with roads and on the technical aids to facilitate work. The aim should be to have "the right system correctly used in the proper place".

1. Cold air pool
2. Cold elevated section
3. Lakeside climate
4. Area subjected to precipitation
5. Stream of cold air
6. Strong wind
7. Area in shadow

This project has been pursued in Sweden for a number of years at the request of the Technical Division of the SNRA, as integrated research and development work between researchers, manufacturers and users.
The Swedish Road and Traffic Research Institute (VTI) participated in the initial development of the climate stations and the survey cars. At the transition of the project to the production stage, Saab-Scania and later FFV-Maintenance took over the further development and manufacture of the VVIS. The survey cars have been further developed and assembled by KUAB, to demand specifications prepared by the SNRA. The main responsibility for climatological matters is borne by BERGAB-Climate Consultans.

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FIGURE 1.11

This model has several drawbacks. It can only be used to forecast cooling periods when the air temperature is warmer than the surface temperature. Also the model is for clear nights only, cloud has not been considered. The model is of limited use therefore, but appears to be the only one of its type in North America. It has not been used for road surface temperature prediction, but rather for agricultural purposes. List (1979) produced a bibliography concerning weather forecasting and snow and ice control in Canada which did not contain a single North American forecasting model. This is not due to the deficiency of the bibliography, but rather to the lack of coordination between the highway authorities and the National Weather Bureau, which has meant that Road Danger Warnings are not generally issued in most States. Instead highway authorities tend to wait for adverse conditions to occur before they do anything about them.

There has been much discussion in North America about the merits and problems of the use of rock salt. Adams (1972) states 'Americans use 6 million tonnes of salt every year to make winter driving safer, but nobody knows if it really does.' (page 3). Overend (1975) concludes a similar article 'Someday, some scientific genius may discover a chemical that efficiently melts snow and ice; does not corrode metal; will not harm foliage or soil nor pollute streams, lakes or wells; and at the same time will be produced to sell at less than $20 a ton. But until that day comes, road crews will undoubtably continue to spread salt on winter roads, though not as much as in the past.' (page 38). Rock salt is still the main de-icing chemical in use in North America, and is likely to remain so. Murray and Ernst (1976) conducted an economic analysis of highway de-icing for the United States Environmental Protection Agency. Their conclusions were rather vague'...the level of salt use should be reduced. The amount of the reduction should be determined on the basis of local conditions.'(page 128). This report, along with many others illustrates how difficult it is to come up with positive methods for reducing the amount of salt spread. This thesis maintains that an improvement in the meteorological forecasting of ice and snow is the most productive solution. Ironically Hode Keyer (1981) in the 'Handbook of Snow' (edited by Gray and Male 1981) hardly mentions the meteorological controls in a section entitled 'Factors influencing the melting rate of snow and ice'. Whereas the editors of a chapter called 'Snowcover ablation and runoff' (page 360) discuss heat balance of snow and ice in great detail. The academic interest is there, but it has been channeled into glaciology rather than into the winter maintenance of roads.

There is a large North American literature concerning the use of automatic sensors for the detection of road surface conditions, however non relates to the forecasting of future conditions. The most advanced sensor system is built in St. Louis by Surface Systems Incorporated (S.S.I.). This system has been used by the author to instrument three motorway sites in the West Midlands as discussed in Chapter 7.

1.6.5 Other Countries

Outside Europe and North America little research has been published apart from work carried out in Japan. Ichihara and Mizoguchi (1970) confirm that the skid resistance of ice is at its lowest when its temperature is at 0°C. Inoue, Baba and Takada (1970) measured road surface temperature automatically every kilometer along a 50 km stretch of road, and claim that this number of sensors is necessary due to variations in road surface temperature caused by topography and road structures. They also mention that they used an infrared thermometer to measure the road temperature between the sensors, and claim that with all this information they can estimate how many permanent sensors are needed along a certain stretch of road. They do not give specific examples but the research was ahead of its time. No meteorological forecasting was attempted.

1.7 Aims of the Thesis

The brief review of international literature given above shows that there is still considerable room for more research to improve winter maintenance practices. This thesis aims to improve the meteorological input to Road Danger Warnings by first constructing a heat balance model for a road surface, secondly testing the model retrospectively to enable tuning of the model, and thirdly testing the model in real-time. This thesis is of little use if it is not applied to the real-world, and hence Chapter 2 is a review of current winter maintenance practices in Britain, and the production of Road Danger Warnings. Chapter 3 presents the heat balance model and all the assumptions that have gone into it. Chapter 4 describes the instrumentation of a site on the M4 motorway to test the model retrospectively. Chapter 5 discusses the translation of the heat balance model into Fortran, and gives a sensitivity analysis of the model. Chapter 6 compares retrospectively the actual versus predicted road surface temperatures for 30 nights when the minimum road surface temperature was less than 5°C on the M4. Chapter 7 discusses the instrumentation of three new sites in the West Midlands and the subsequent testing of the model in real-time during the winter of 1982/83. Chapter 8 assesses the potential of the model for use in the production of Road Danger Warnings for the future, and reviews the real-time production of Road Danger Warnings for West Midlands County Council in 1983/84.

CHAPTER 2 MOTORWAY WINTER MAINTENANCE IN ENGLAND

2.1 Introduction

Winter maintenance of motorways and major trunk roads in England is the responsibility of the Secretary of State for Transport. The actual carrying out of winter maintenance however is delegated to 60 County Councils and London Boroughs who are agent authorities (AAs) for the Department of Transport (DTp). These agent authorities also maintain their own trunk and local roads but pay for these out of local rates. The maintenance of motorways and major trunk roads is paid for by the Department of Transport, which has separate branches for Northern Ireland, Scotland and Wales.

After each winter the agent authorities submit a claim for expenditure which is usually paid without question by the Department. This "blank cheque" approach is based on mutual trust and experience but it seems that each agent authority has developed its own set of maintenance procedures, some of which are much more expensive than others. Indeed, agent authority costs have become fossilised, in that large claims in the past produce large estimates in the future. The need to standardise these practices has been recognised by the Rayner Scrutiny carried out in 1981 entitled - "Winter Maintenance of Trunk Roads and Motorways in England" (Rayner 1981). Sir Derek Rayner (former Chief of Marks and Spencer) has undertaken a number of studies for the Thatcher government designed to eliminate 'waste' from government expenditure. Is there any waste in winter maintenance? It is worth examining this scrutiny in detail in order to analyse the full economic basis of winter maintenance, which will enable the relative importance of Road Danger Warnings to be more clearly assessed.

2.2 The Rayner Scrutiny of Winter Maintenance

The terms of reference of the Scrutiny were set out as follows: 'To examine the methods adopted by a representative sample of local authorities for the winter maintenance of trunk roads and motorways in England with a view to securing:

(i) the maximum economy and value for money, subject to the essential needs of safety;

(ii) effective control over expenditure;

(iii) a good understanding between the Department (of Transport) and its agent authorities.

The study should include an examination of the scope for alternative methods of providing this service such as the use of private sector contractors.'

The scrutiny presents a thorough airing of the current problems that face efficient winter maintenance. Twenty-three recommendations for action to improve efficiency and cut costs are put forward. Most of the recommendations, which are designed to produce a saving of approximately 10% on the current average budget of £11m, are concerned with labour and plant costs, and only two refer to Road Danger Warnings. The twenty-three recommendations, listed in Table 2.1 give a good idea of the width of analysis of the scrutiny. Such a comprehensive list should produce some savings if all the recommendations are put into practice.

The scrutiny can be split into three main sections which will be examined in turn. First there is a review of the need of winter maintenance; secondly an analysis of current practice as discovered in an interesting examination of 10 agent authorities; and thirdly the proposed recommendations.

Table 2.1 Table of Recommendations

1. Statement of service required on DTp roads;
2. Publicity required;
3. Development of a code of best practice;
4. Analysis of motorway fleet for possible economies;
5. Observance of salt spreading rates;
6. Notification of salt holdings;
7. Contracts between agent authority and Met. Office;
8. Annual discussion of reaction to weather reports;
9. Single manning of salting vehicles;
10. More uniform and less extensive labour coverage;
11. More reliance on police patrol observations of road conditions;
12. More widespread adoption by agents of economical plant maintenance;
13. Abandonment of DTp's operational supervision in normal winters; regional emergency arrangements;
14. More detailed outturn statements for annual discussion with DTp;
15. Routine copying of the agent's financial progress reports to DTp;
16. Separate consideration of winter maintenance funding and performance;
17. Revised cashflow management for winter maintenance;
18. More liberal attitude towards use of motorway plant on adjacent roads;
19. Transfer of DTp plant to agent authority ownership;
20. Review of specialist Emergency Snowplough Reserve;
21. Performance specification for motorway plant;
22. Timing of a fleet transfer;
23. Provision of service by direct DTp management of contractors rejected.

2.2.1 The Need for Winter Maintenance

1. The terms of reference of the scrutiny made it clear that economy was not to be sought at the cost of a reduction of safety. Also it appears that there is no danger that winter maintenance will be withdrawn or even severely cut because:

   '.......the general effect of case law is that he (the Secretary of State) is vulnerable to legal action if he declines to act or make adequate arrangements..........to keep his roads open.' (Section 5.2)

   There are no published details of how many such cases arise each year, but clearly this places additional pressure upon maintenance engineers to salt their roads 'just in case'. The frequency of oversalting for this, or any other reason cannot be checked until road surface conditions are monitored. Of course the monitoring of road surface conditions would make legal arguments more clear. The report does not suggest that oversalting is taking place: 'We had no representations that the current service was excessive.' (Section 5.4). This was probably due to the fact that the Scrutiny was conducted as an internal exercise within the Department of Transport and associated agent authorities. It has been suggested by Laxen (1977) and Thornes et.al. (1977) that up to twice as much salt is being spread than is actually needed. In the absence of road surface data however this remained a hypothesis; a hypothesis that has been tested and confirmed in the West Midlands during the winter of 1982/83 as discussed in Chapter 7 of this thesis.

2. The Scrutiny goes on to justify current levels of winter maintenance under the heading of 'safety and public expectations' but is critical of driving standards:

'The driving public no longer makes sufficient allowance for winter conditions. Ice and frost are particularly treacherous though motorways in fog suggest that drivers discount overt danger as well. Expectations, encouraged by improved, high speed roads, have reached the point where winter travelling expectations equal those of summer......' (Section 5.1)

The Scrutiny admits however that the publicity surrounding winter maintenance is poor, 'leaving the public in optimistic ignorance' (Section 5.4). Certainly the public deserve more information about road surface conditions. Recently for instance the use of 'cats eyes' with liquid crystal reflectors that change colour according to their temperature, has been suggested. This would be a relatively cheap way of informing the motorist that the road surface had fallen below 0°C, but would not inform the motorist whether or not the road has been salted, or indeed whether or not ice was likely to be present. Once road surface temperatures are being measured it would be a simple task to display the actual temperature plus a warning sign on the speed restriction signs. Experiments are currently taking place in Bedfordshire on the M1 to provide a more detailed explanation of road conditons using electronic warning signs. The Scrutiny does not examine technical improvements however:

'We reviewed recent technical developments, but found them at present inadequate to replace operational judgement or a driver's visual appreciation of conditions. But since we favour less reliance on shift coverage of strategic routes the technical refinement of ice prediction may have an increasing though supplementary importance in helping operational management.' (Section 5.7)

This is an important statement in that it moves well beyond the relaying of technical information to the public. It hints that ice prediction might have an increasing role to play. This is a very conservative view of the role of improved ice prediction. Road sensors and real time computer modelling can certainly improve operational management.

In that the Scrutiny was designed to cut costs immediately, it is not surprising that research and development has not been examined in detail as such developments take time to come to fruition.

3. The importance of reducing delay due to wintery conditions and reducing the number of accidents caused by such conditions is discussed in Section (5.5):

'Some 4.2m vehicles travel on motorways and trunk roads each day. DTp has computed an average cost per vehicle at 1979 prices for 1 hour's delay on the motorway was £2.67. If applied to the whole DTp network that suggests that an artificially imposed delay in salting would cost on average nearly £1/2m per hour.'

These figures are only estimates but nevertheless clearly show the amount of money at stake in the benefit/cost ratio. Using these figures an artificial delay in salting which caused motorways to be blocked for 24 hours would cost £12m which is more than the average £11m spent on the winter maintenance of motorways in a year.

These delay costs are felt most of all by industry, and in view of Sir Derek Rayner's commercial interests the following paragraph is interesting:

'Commercial interests would vociferously object to artificial delay in treatment. Many companies operate tight time schedules in trunk freighting and distribution. This has become possible only with motorway network development and a high standard of service offered. Erratic delays to trunk service vehicles would disrupt the whole operation with ripple effects back to production and forward to local delivery. Winter is reckoned to be the peak period for goods movement.' (Section 5.6)

The current level of winter maintenance appears to be doing its job, as far as keeping the motorways open is concerned. Palutikof (1981, 1983) has analysed the effect of severe winters on road transport and concludes that the main effect is on private journeys: 'Goods transport is less disrupted, presumably because journeys are postponed rather than cancelled.' Motorways and major trunk roads have only been closed for very short periods in the past due to blockage by snow and ice.

4. Moving on to safety the report states:

'The attributed cause of accidents is often subjective, understressing driver responsibility. But delay in treatment extends the opportunity for accidents, whose 1980 average costs are estimated as £119,300 per fatality and £5,040 per serious injury......During the 5 years from 1975/76, the number of winter accidents on DTp roads was stable, while the volume of traffic increased, resulting in an 8% decrease in rate of accidents per vehicle - kilometer.' (Section 5.8)

Attempts to put a price on human life have been extensively questioned (e.g. Adams 1974) but attempts to reduce the accident rate have not. The number of accidents that have been attributed to icy roads does not reflect properly the number of accidents that would have occured had winter maintenance never been attempted. This question was examined in the previous chapter but at the costs per fatality quoted above the £11m spent on winter maintenance of motorways is worth about 90 lives.

5. As regards the use of salt the report states:

'We can not find a preferable alternative to ground rock salt as melting agent.' (Section 6.1)

Salt has been under attack particularly in North America for its corrosive and environmentally damaging side effects. These costs are not borne by the Department of Transport however! Therefore they do not enter the benefit/cost analysis in the Scrutiny. For instance as far as corrosion is concerned:

'The avoidance of corrosion has been quoted as a possible "saving" if salting was eliminated or greatly reduced. Elimination is impractical and the saving on reduction would be difficult to quantify, particularly as technical study, though inconclusive, suggests that the marginal rate of corrosion is not uniform with increasing volume of salt.' (Section 6.5)

Figure 1.6 shows that the most severe corrosion is in the East of England where on average less salt is spread than in the upland areas of the North and West. The annual cost of vehicle corrosion has been estimated by Valery (1973) to run to several hundred million pounds per year. Murray and Ernest (1976) estimated that the 9 million tonnes of salt spread in the United States at a cost of $200m (in 1976 prices) caused the following:

'.......the contamination of water supplies.....$150m; those for vegetation at possibly $50m, for cars $2,000m, for bridge decks $500m, and for utilities more than $10m.' (p89)

These costs are only approximations but nevertheless if they are of the correct order of magnitude then they cannot be ignored. Salt must only be spread when necessary and to this end improved Road Danger Warnings must be sought.

2.2.2 Financial Analysis

1. The Scrutiny assumes that the benefits of winter maintenance far outway the costs, and that the costs can be reduced by improved management:

   'Trust in agent management has declined into laissez faire....... Financial control has been inadequate.'

   There has been a lack of analysis of agent spending on winter maintenance probably due to the fact that the financial figures have been absorbed under general headings of expenditure on all maintenance. The Scrutiny presents for the years 1975-80 the first major financial breakdown of costs that has ever been attempted. For instance in the winter of 1979/80 the total cost for motorway maintenance in England (Table 2.2) was £11,521,000 comprising:

Table 2.2 The Cost of Motorway Winter Maintenance in England

		(£000)
(a)	allocations paid to agent authorities (covers salt, fuel and labour)	7,585
(b)	agent authority management (8% of (a))	607
(c)	Department of Transport staff effort	
	(i) in H.Q.	20
	(ii) in regional offices	46
(d)	Department of Transport plant	
	(i) plant development	2,681
	(ii) maintenance and stores	301
	(iii) staff effort	281
	Total	£11,521

Each year the Department of Transport allocates sums of money to each agent authority to cover all maintenance expenditure in the region. Winter maintenance is but one item out of twenty:

'The split between winter maintenance and other expenditure was usually left to regional decision though for 1981/82 H.Q. have suggested sub-allocations. Regional autonomy is much valued as tailoring funds available to particular regional needs.' (Section 4.3)

According to the Scrutiny 'winter expenditure has not been audited in living memory.' (Section 4.6)

2. To illustrate this patchy and loose supervision the Scrutiny examined 10 county council agent authorities to compare winter maintenance

expenditure. Just as Hornigold (1970) and Blackmore (1977, 1983) found from questionnaire analyses of agent authorities, winter maintenance practices are diverse and often unaccountable. The ten counties are not named directly by the Scrutiny but they are easily identifiable. The results of this analysis have been examined elsewhere by the author (Thornes 1982) but they are worth discussing here in more detail.

The sample counties were chosen to give a 'wide spectrum of climatic and physical diversity, standard practices and unit spending rates' (Section 7.3). Table 2.3 identifies the counties from the descriptions of each given in the Scrutiny.

The Scrutiny calculated the amount spent on motorways and trunk roads per kilometer of road. The length of road is expressed in kilometers of single carriageway equivalent (SCEKM) which is the standard unit used by the Department of Transport. In other words if a road is three lanes wide it is classed as being three times as long as an equivalent length of single carriagway. Table 2.4 shows how the spending rates vary between counties.

Figure 2.1 shows that there is a weak relationship between the spending per SCEKM, and the number of SCEKM in each county. The correlation coefficient for the nine counties with motorways is 0.586. This is just significant at the 5% level (critical value for 7 degrees of freedom is 0.582). This suggests that the more miles an agent authority has to maintain the greater are its unit costs. The correlation coefficient for trunk roads is not anywhere near significant at 0.018 (critical value of 0.549 at the 5% level

Table 2.3 Descriptions of the Ten Counties in the Sample

County A: northern, mountainous, without motorways, very high spending rates; deeply involved in last winter's allocation dispute (Northumberland)

County B: northern, mountainous, with spine motorway, high spending on motorways but average on TR's. (Cumbria)

County C: very large, rural, northern part mountainous though strategic route is in lowland; spending rates very low (N. Yorkshire)

County D: mountainous, northern, metropolitan; high spending rates (W. Yorkshire)

County E: midland, part upland, fairly exposed; higher TR than motorway spending rates (Derbyshire)

County F: midland, undulating; motorway spending rates (low) but average TR spending (Warwickshire)

County G: typical home county, with 2 distinct motorway sections; high motorway spending but low TR rates (Buckinghamshire)

County H: lowland west-country with spine motorway sections; lower than average spending rates (Somerset)

County I: south coast, high spending on motorways and low spending on TRs (Hampshire)

County K: south coast, exposed with spine motorways; high spending rates on motorway and TRs (Kent)

FIGURE 2.1 SURVEY OF COUNTY SPENDING PER SCEKM VERSUS SCEKM OF ROAD (Rayner 1981)

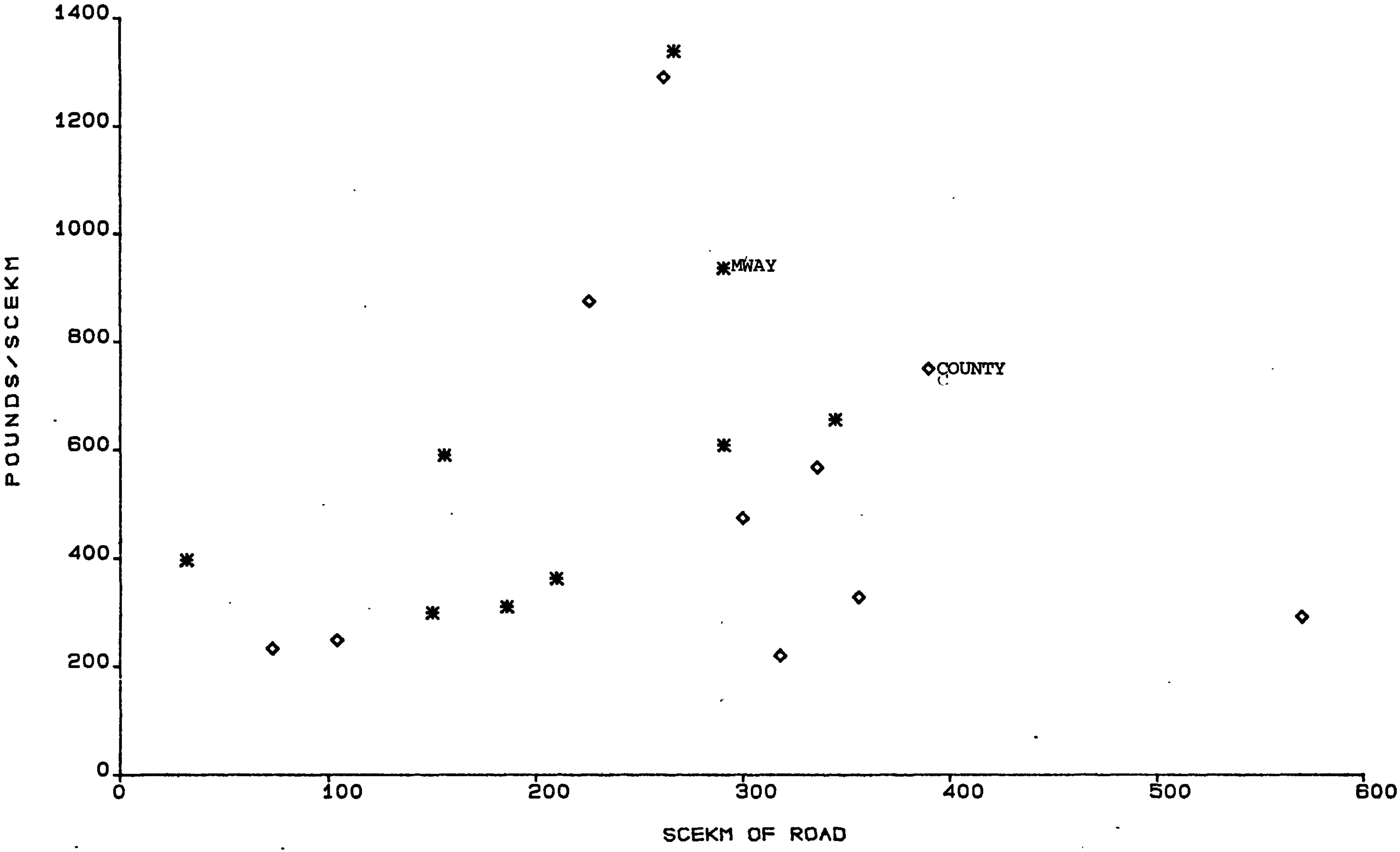


Table 2.4 Spending Rates per SCEKM for Each County in 1979/80

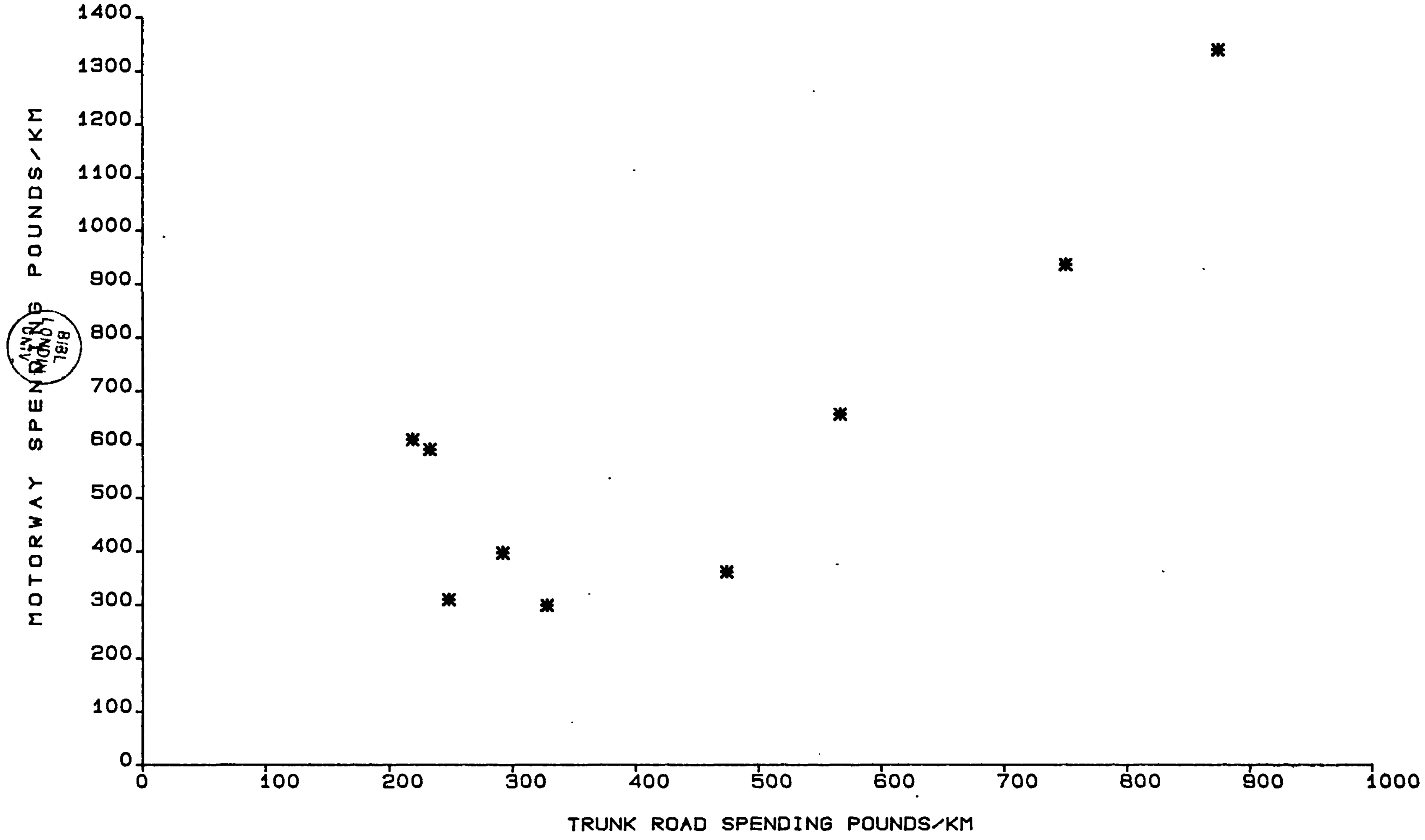
	km of M/W equiv.	km of TR equiv.	M/W £/km	TR £/km
Northumberland	-	262	-	1291
Cumbria	291	390	937	751
N. Yorkshire	32	570	397	292
W. Yorkshire	267	226	1339	875
Derbyshire	210	300	362	474
Warwickshire	150	356	299	328
Buckinghamshire	156	73	590	233
Somerset	186	104	310	248
Hampshire	291	318	608	219
Kent	345	336	656	567

TR: Trunk Road M/W: Motorway

for 8 degrees of freedom). The very low cost per SCEKM for trunk roads produced by North Yorkshire, which has the most trunk roads to look after of all counties sampled, tends to lower the correlation coefficient substantially. The other 9 points on the graph are very similar to the motorway figures. Generally speaking therefore it seems that, with one notable exception, small is beautiful and cheap!

Figure 2.2 compares spending on motorways with spending on trunk roads for each county, and shows that 7 out of the 9 counties plotted spent more on their motorways than on their trunk roads. There is a positive relationship with a correlation coefficient of

FIGURE 2.2 MOTORWAY VERSUS TRUNK ROAD SPENDING FOR NINE COUNTIES



0.825 which is significant at the 1% level (critical value for 7 degrees of freedom at 1% is 0.798) showing that the bigger spenders on motorways tend to be the big spenders on trunk roads also. This is to be expected in that the same Road Danger Warnings are received for each.

The discrepancies in spending rates between for instance North and West Yorkshire are difficult to explain. Table 2.5 goes some way to explain where the main differences lie:

Table 2.5 Breakdown of Costs for North and West Yorkshire

	Labour	Plant	Salt	Total
(i) Motorways				
N. Yorkshire	85(21%)	117(29%)	194(50%)	397(100%)
W. Yorkshire	717(54%)	407(30%)	212(16%)	1337(100%)
(ii) Trunk Roads				
N. Yorkshire	51(17%)	91(31%)	150(52%)	292(100%)
W. Yorkshire	331(38%)	320(37%)	224(25%)	875(100%)

(all figures are £/SCEKM)

It can be seen immediately that West Yorkshire spend far more on labour and 'plant' for motorways and trunk roads. The cost of salt per SCEKM is not that different, but presumably West Yorkshire use more salting vehicles in order to salt their roads quickly. An improvement in Road Danger Warnings is unlikely to reduce salt costs for West Yorkshire in percentage terms, as North Yorkshire spend more than 50% of their budget on salt. Nevertheless the labour costs are so great in West Yorkshire that better Road Danger Warnings would reduce the number of outings, and hence save money.

The overall expenditure has been averaged for the three northern counties (for which detailed information is available) and compared with the five southern counties. These figures are given in Table 2.6:

Table 2.6 Comparison of Expenditure of Northern v Southern Counties

(i) Motorways

	Labour	Plant	Salt	Total
Northern(C-E)	355(51%)	183(26%)	160(23%)	698(100%)
Southern(F-K)	234(48%)	119(24%)	139(28%)	493(100%)

(ii) Trunk Roads

	Labour	Plant	Salt	Total
Northern(C-E)	179(33%)	189(34%)	179(33%)	547(100%)
Southern(F-K)	69(22%)	145(45%)	105(33%)	319(100%)

For motorways the percentage figures are remarkably similar, showing that 50% of costs are spent on labour. The total figures are greater for northern counties than for southern counties as might be hypothesised for geographical reasons. Remarkably on trunk roads exactly a third of costs is spent on salt for both regions. The larger expenditure on 'plant' for trunk roads is not comparable with motorways because of the plant provided by the Department of Transport for motorways. Nevertheless the northern counties appear to spend significantly more on labour than the southern counties.

The Scrutiny also examines these figures in detail, and offers the following comments:

'This very wide diversity in spending rates among sample counties and between motorways and trunk roads in the same county, partly results from climate, relative exposure to wind, topography, traffic volumes, and accessibility of labour.....coverage and response time attempted, labour agreement, rates of salt application, type of organisation and reliability of local authority cost accounting.' (Section 7.5)

Quite an extensive list! Also the reliability of the data is questionable. 'Both the Department of Transport and sample counties had difficulty in providing accurate detailed data - itself an illustration of a major weakness in the service.' (Section 7.6) If all counties had equal difficulty it is probable that the figures are nevertheless comparable.

An interesting point emerged in the discussions with the sample counties that:

'Snow clearance in most winters is far less important than precautionary salting.' (Section 7.6)

If, as this thesis maintains, far too many Road Danger Warnings for precautionary salting are issued then immediate savings of labour and salt would be made possible by improved forecasts of icy roads.

3. The climate of a county should determine the level of plant required for winter maintenance. The weather determines labour and salt costs. Altogether in 1979/80 labour and salt accounted for 75% of the costs of motorway maintenance and 65% of the costs of trunk road maintenance. The recommendations of the Scrutiny are only expected to save about 10% of total costs, a reduction of precautionary saltings due to better Road Danger Warnings of one third might potentially

save one third of 75%, i.e. about 20% taking into account the fixed costs of standby and shift payments.

4. The management of winter maintenance is usually the responsibility of the county surveyor, and the Scrutiny is aware that the surveyors judgement dictates the spending rates also:

'The organisational role of the county surveyor cannot be overstressed. He agrees with his Council Committee the winter maintenance policy for county roads and, in default of Department of Transport instructions, for Department roads as well; he establishes the required organisation; he sets out route treatment priority; he decides the 'winter maintenance season'; he directs operations in severe conditions; and he negotiates the labour agreement. Each county surveyor interviewed would not recommend practices except for his own county conditions, yet similar counties are differently organised, pointing to marked autonomy of professional judgement:

The key decision of when to salt or not in each area is usually delegated to the county divisional surveyor, whose local knowledge and experience is vital. Even here practice is diverse: counties C, G. K and until recently D salt when weather forecasts indicate a likely temperature of less than 0°C; counties B and E salt when falling temperatures reach 34°F while counties H and I salt when falling temperatures reach 2°C (35°F); county F seeks to avoid salting in overtime by salting whenever possible during normal hours.' (Sections 7.16 - 7.17)

The Scrutiny is not clear as to whether it is referring to air or road temperatures, but presumably it is discussing road forecast temperatures. The diversity of practice is staggering and is surely not just related to lack of Department of Transport control. The major reason for such autonomy is the lack of feedback as to the success or need for the salting of roads on a particular night. At present the only feedback is the occurence of accidents on unsalted roads. In 1970 there were 10,432 accidents reported when the road surface was classed as icy (Codling 1974). This was 3.9% of all accidents in 1970 reported. How many accidents would have occurred if there was no winter maintenance? That figure of 10,432 represents the nights presumably when ice was not forecast or the county surveyor decided not to salt. If road surface temperature and wetness were actually measured then the county surveyor would have immediate feedback as to the success of his decision, as well as extra information to help him to decide whether or not to salt in the first place. This would immediately help to standardise winter maintenance procedures, because the county authorities could be asked to submit details of road surface conditions on the nights that they salted (or decided not to salt). Armed with such information comparisons between counties could immediately pinpoint spending differences due to climate, topography, bad decision etc.. Otherwise counties will continue to hide behind the excuse that their particular region demands special attention.

5. The recommended spreading rates for salt were reduced in 1976 from the imperial rates of $1/2/oz/y^2$ and $2\ oz/y^2$ (equivalent to 17 and 68 g/m^2) to the metric rates of 10 g/m^2 and 40 g/m^2. The former figures are for precautionary salting and the latter for treatment of ice that has already formed, or snow that has already fallen.

The Scrutiny revealed however that some counties still use imperial rates:

'In precautionary salting for icy conditions about half of the sample counties claim to attempt the Department of Transport's recommended rate of spread, which is achievable with relatively dry salt. But some counties still use imperial rates...... In salting for other conditions there is a wide and inexplicable variation in the rate of spread attempted by individual counties.' (Section 7.22)

These discrepancies and several others already discussed led to the first recommendation of the report (See Table 2.1) which suggested the publication of a new code of practice for winter maintenance. This has been published (Department of Transport 1981) and will now be discussed along with the other recommendations.

2.2.3 The Recommendations

There is not sufficient space to discuss all the recommendations, so that the discussion is limited to those that concern directly the Road Danger Warnings issued by the Meterological Office. Recommendations 1 and 3 (Table 2.1) have already been carried out. The 'Statement of Service and Code of Practice' issued in November 1981 was too late to have a great impact on the practices of the 1981/82 winter, but in that it was sent to all agent authorities it was hoped to standardise maintenance procedures from then on.

The code defines three distinct periods for winter maintenance:

(1) High period - December, January and February during which 24 hour cover should be provided in order to be able to achieve a two hour

maximum treatment time.

(2) Low period - November and March, if possible precautionary action should take place during normal working hours. Call-out arrangements, with operatives off duty, should be used outside normal hours.

(3) Marginal Period - October and April, plant should still be available but treatment should only be carried out in 'exceptional circumstances.'

These periods are reasonable and the code does state that 'Exceptionally when severe conditions are prolonged during these periods (low and marginal) it may be necessary to implement high period arrangements.' Of course the British climate is unpredictable and it could be argued that these periods reflect the likelihood of snow rather than icy roads. Nevertheless it is about time that the season for maintenance was standardised. Table 2.7 shows that the maintenance season for most counties was different in 1980/81.

By standardising the maintenance season it should also be possible to compare spending rates more easily, especially if all the authorities adopt the new overnight cover suggestions, and single man their salters. Previous codes of practice have obviously failed to achieve uniformity, presumably because authorities were not asked to provide details of their habits. With this code authorities have to report what they are doing and if they object to the suggested periods they have to get permission from the Department of Transport to go their own way.

Having set out the maintenance season and cover, the code then offers guidelines for treatment of ice and snow. Here the code is at

Table 2.7 Summary of Sample County Services 1980/81 (Rayner 1981)

County	Normal WM Season	Overnight Cover MWs	Overnight Cover TRs	Manning of salters
A	Nov.-mid March	-	continuous	double
B	9 Nov.-end Feb.	standby	standby	double
C	1 Nov.-end March	standby	standby	single
D	1 Nov.-end March	continuous	continuous	single
E	mid Nov.-mid March	continuous	both	single
F	1 Oct.-end April	standby	standby	single
G	"winter period" (sic)	continuous	standby	double
H	early Dec.-late Feb.	continuous	both	single
I	1 Nov.-end March	continuous	standby	single
K	1 Nov.-end March	both	standby	double

its vaguest. It is obvious that the meteorology of ice formation and snowfall is far from understood as discussed in Chapter 1. This is the biggest weakness in the winter maintenance procedure. Until the Department of Transport install road surface temperature sensors for each agent authority the salting decision will remain a mysterious and inefficient piece of management. These sections of the code of practice need to be rewritten.

Recommendation 7 relates to the contracts between agent authorities and the Meteorological Office. Not all agent authorities take the Road Danger Warning service offered by the Meteorological Office. Hornigold (1970) produced a map of the various reasons for activating salting in the counties as shown in Figure 2.3. The main reasons why the Road Danger Warning service is under used is that the warnings are based purely on air temperatures and they are not local enough for

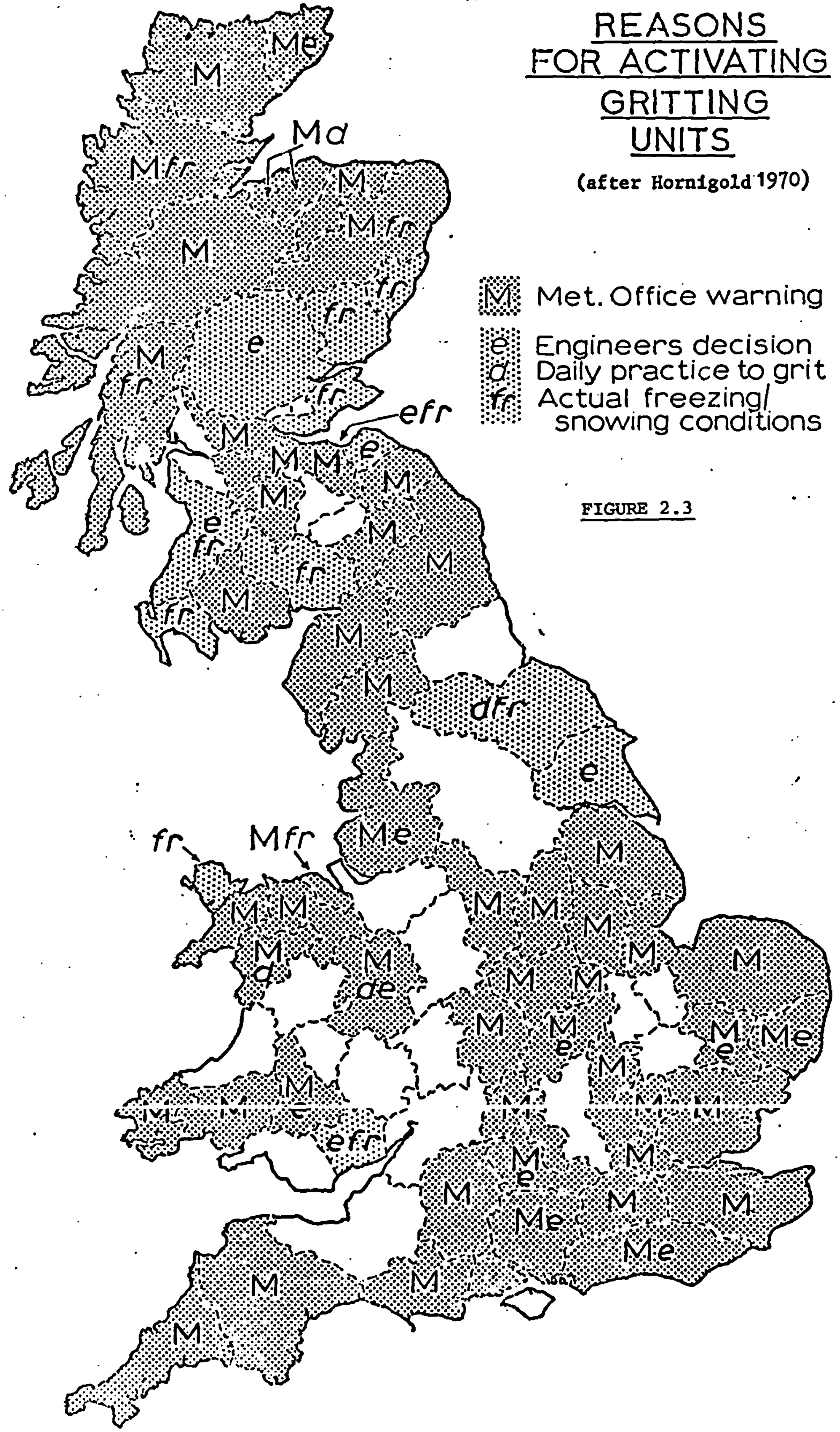

REASONS FOR ACTIVATING GRITTING UNITS
(after Hornigold 1970)
M Met. Office warning
e Engineers decision
d Daily practice to grit
fr Actual freezing/ snowing conditions
Me
M
Md
Mfr
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FIGURE 2.3

'geographical idiosyncracies' to be taken into account as discussed elsewhere in this thesis. The Scrutiny states:

'We recommend that divisional surveyors be encouraged to develop district personal contacts with regional weather offices and that those agent authorities who do not now take Meteorological Office verbal weather appreciations do so.' (Section 8.10)

At present most Road Danger Warnings are issued by telex which saves the local weather centres time and money. A personal phone call to each authority is time consuming. The London Weather Centre for instance issues warnings to more than 60 local as well as county authorities. The county authorities will have to be given a special service if verbal contact is to be maintained. This will be more expensive than the current annual fee for Road Danger Warnings of about £200.

Recommendation 8 suggests that each year after the maintenance season is over the agent authority should discuss the occasions when the weather forecast was inadequate:

'The decision to salt is never going to be perfectly judged. Some salting will prove to have been unnecessary while a decision not to salt may be followed by freezing, and an emergency call-out. Each county surveyor should have a record of such cases for annual discussion with the Department of Transport.' (Section 8.11)

This is wishful thinking! If road surface conditions are not monitored, the many occasions when salting was carried out unnecessarily will not be detected. Only obvious occasions like heavy snowfalls will be remembered, or if there was a series of accidents due to icy roads. This is yet another reason for the monitoring of road surface conditions.

Section 8.12 of the Scrutiny estimates that a 10% reduction in salt use would save £200,000 per annum. This reduction will be hard to quantify unless some index of winter severity can be devised. Perhaps the index suggested by Hulme (1982) discussed in the previous chapter could be used. Unfortunately it is based on air temperature rather than road temperature, but it could be adapted if road surface tempertures are measured.

The other recommendations are not directly concerned with Road Danger Warnings and hence will not be discussed here. Overall, the Scrutiny is comprehensive in its coverage though it has yet to be shown that any of the recommendations here had any impact, or that the reaction of agent authorities has been positive. An initial response from Warwickshire (personal communication) is that they will continue much as before. Although Warwickshire was not one of the expensive authorities in the survey they claim that a spreading rate of 10 g/m^2 is too little, and that they have found that precautionary salting of that magnitude sometimes has to be repeated in the early hours of the morning as the salt has been splashed, blown or removed from the surface by traffic. They are also very conscious of the possibility of legal action if there is an accident on an untreated icy road. Therefore, they are always going to be over cautious. With the measurement of road suface temperature this nagging fear could be eliminated.

This long discussion of the Raynor Scrutiny has been very useful. Had the Scrutiny not been written, or had the Dept. of Transport not had it commisioned, the same ground would have had to be covered to show how important Road Danger Warnings are to winter maintenance.

2.3 Road Danger Warnings and Winter Maintenance on Motorways

It has already been stated that the overall cost of winter maintenance for motorways and trunk roads is on average about eleven million pounds. The cost of Road Danger Warnings on average is about £170 per annum per authority. There are 60 agent authorities and therefore the total amount of money charged by the Meterological Office for motorways is the tiny sum of around £10,000. This represents 0.1% of the winter maintenance budget! It is no wonder that there is a general dissatisfaction with the Road Danger Warnings for specific areas. The Meterological Office are not going to spend much time or money to localise the service. During the winter of 1982/83 102 Road Danger Warnings were issued by Elmdon Weather Centre to Hereford and Worcester County Council, which represents a warning approximately 2 out of every 3 nights during the winter period.

Current Road Danger Warnings are over cautious, as will be shown in Chapter 7 when forecast minimum road surface temperatures for the M5 motorway are compared with actual observations. What is the main cause of error? A full discussion of this problem is given in (Thornes and Blackmore 1977; Thornes, Wood and Blackmore 1977 and Blackmore 1983), but briefly Road Danger Warnings are based on forecast minimum air temperatures which can be very different from actual minimum road surface temperatures. This thesis presents a new forecasting technique which uses actually observed road surface temperatures. The Meteorological Office cannot afford to measure road surface temperatures in view of the small amount of income they receive from the sale of Road Danger Warnings.

Hence it is up to the Department of Transport to pay for the installation of sensors. The economics will be discussed in Chapter 8, and the new method of forecasting road surface temperatures up to 24 hours ahead is outlined in the next chapter.

CHAPTER 3 MODELLING THE ATMOSPHERIC BOUNDARY LAYER ABOVE A MOTORWAY

3.1 Introduction

The task of improving the forecast of ice formation on motorways is beset with difficulties. Current Road Danger Warnings issued by local weather centres are simple to produce in that they are merely subjective extentions of the minimum air temperature forecast. They take the forecaster perhaps a few minutes to produce and, of course, because the forecasts are unverifiable they do not cause much worry to the duty forecaster. Any system put forward to improve this forecast is unlikely to be accepted if it requires considerably more effort on the part of the forecaster, even if it can be shown to be more accurate. What is needed is a very simple and quick forecasting model that allows the forecaster to experiment with ideas. Microcomputers are the ideal vehicle for such a scheme but it is immediately apparent that local weather centres do not yet have the microcomputers to run programs which are both sophisticated and user friendly, in real time. The model to be outlined in this chapter is meant to be microcomputer based and the implications of such a development for weather centre staffing is discussed in Chapter 8.

3.1.1. Introduction to Planetary Boundary Layer Models (PBL)

Atkinson (1983) gives an excellent review of the history of dynamic boundary layer modelling but concludes:

'small scale flows modellingthe PBL present particulary formidable problems of both physics and computing. The solution of these problems will continue to be a major priority of international meteorology throughout the 1980's.' Atkinson (1983) is concerned primarily with mesoscale airflow models which he distinguishes from chiefly one-dimensional models concerned with the vertical variations in the PBL. Traffic on a motorway presents an extreme complication to small-scale flows! Very few of the mesoscale models are concerned with the prediction of surface temperatures, and the only work Atkinson (1983) references with regard to surface temperatures is that of Deardorff (1978). Deardorff compared several one-dimensional models for predicting ground surface temperatures and found that the methods proposed by Bhumralkar (1975) and Blackadar (1976) were the most efficient. However both these approaches are primarily concerned with the accurate modelling of heat exchange within the ground, and contain several simplifying assumptions concerning net radiation, heat exchange with the air and evaporation, that render them impractical for operational forecasting development.

Landsberg (1981) distinguishes between 'static' models and 'dynamic' models when considering approaches to the simulation of the urban heat island. Static models are the simplest type of heat balance models, and are sometimes called zero-dimensional (Schneider and Dickinson 1974).

McBean et.al. (1979) have divided PBL models into the following two categories:

(a) research models for studies in atmospheric turbulence and the structure and physics of the Planetary Boundary Layer;

(b) Operational models for various applications.

They continue:

'The basic difference in approach between the two kinds of models can be illustrated by the following table showing the CPU-time needed for running a 24 hour forecast of PBL-simulation with different numerical PBL models:

(a)	Deardorff's model (1974)	
	3-d model, 64,000 gridpoints	350h/24h forecast
	t = 6 seconds, CDC-7600	
(b)	Pielke's sea breeze model (1973)	6h/24h forecast
	No "physics" 3-d CDC-6600	
(c)	Tapp and White's sea breeze model (1976)	52m/24h forecast
	3-d No "physics" IBM 260/195	
(d)	Long and Shaffer's model (1975)	10m-15m/24h forecast
	2-d "All physics" IBM 360/195	
(e)	One-dimensional models (Yu, Yamandarand	
	Mellor, Bodin etc.)	$\sim\frac{1}{2}$m/24h forecast
	"All physics" IBM 360/195'	

McBean et.al. (1979) state that for operational purposes only model (d) and the models mentioned in (e) are suitable for operational forecasting simply because of the run time involved. In reality if 'scenario' forecasting is required, i.e. the running of a model several times to test out different boundary conditions, then only zero or one dimensional models are feasible, particularly when the relatively slow speed of a microcomputer is compared to that of an IBM 360.

A motorway environment is far from a perfect meteorological site. Apart from the effect of the artificial structure of the motorway on the boundary layer, there is the effect of traffic to be considered. Very little work has been done to include traffic in energy balance models and like advection it is ignored in one-dimensional modelling, but as McBean et.al. (1979) state:

'In many applications we meet situations that are far from the idealized conditions of the laboratory and simplified theories, but many of these processes might still be incorporated if we make use of approximate numerical models' (p81).

Hunt and Simpson (1982) review research into boundary layer theory for non-homogenous terrain. They state at the beginning of their review:

'One of the main limitations of the discussion here is the inadequate treatment of the synthetic effects of two or more surface disturbances occurring simultaneously, e.g. changes of roughness and temperature, or roughness and elevation, which can be quite dramatic.' (p270)

A motorway presents several changes simultaneously to the wind as it approaches; differing surface temperatures and wetness, traffic moving at up to 70 miles per hour in opposite directions, and varying heights of obstruction. Such an environment can never be modelled completely - to do so one would have to forecast traffic flows as well! Hence we have to simplify as best we can, and use a model that is easy to adapt and quick to run on a microcomputer. The worth of the model will be tested by comparing predictions with observed road surface temperatures. For these reasons the static, zero-dimensional model proposed by Outcalt (1971) has been adapted for the purposes of this thesis.

3.2 The Boundary Layer Over a Motorway

The atmosphere is rarely at rest, and as the air moves in response to pressure gradients, the molecules near the surface interact with this surface and are impeded in their horizontal movement. Although air molecules are separate entities, for modelling purposes the air is usually considered to behave as a fluid. In real fluids molecules constantly link and break off from adjoining molecules so that there is physical linkage between molecules. Strictly speaking in air this is not the case. Thus air molecules hitting the surface of the earth should not exert a direct physical influence on molecules several metres above them. However it has been observed empirically that the wind speed above a surface increases logarithmically with height in neutral stability, thus apparently the air molecules do interact in some way up to a height of tens of metres. If we consider an infinite flat smooth plain it is only the air molecules within a few centimetres of the ground that are likely to collide with the ground if the flow of air is smooth. Some molecules near the surface will collide and stick to the surface, others will bounce off back in the direction in which they came and collide with air molecules moving in the direction of the wind, thus causing what is called turbulent sheer. The boundary layer is the layer in which this turbulent sheer has an effect, and the height of the layer depends upon the speed of the wind and the roughness of the surface. All surfaces are rough of course in relation to the size of air molecules.

The hypothesised boundary layers for a motorway with traffic differ according to whether the traffic is moving at right angles to the wind, or parallel to it. Also the boundary layer is complicated by the fact that the traffic is moving in different directions in the two carriageways.

The overall effect of the traffic however is not such that it dominates the wind. Rao et.al. (1979) have shown that the wind is normally only accelerated or decelerated in the lowest eight metres of the atmosphere.

In winter, assuming neutral lapse conditions, the height of the mechanical boundary is probably no more than 20-30 m above a motorway depending upon the wind speed. The thermal temperature gradient will be very small over this height, with the dry adiabatic lapse rate (DALR) of 1°C per 100 m, the temperature at 30 m will only be about 0.3°C different from the temperature at screen height (1½ m). The heat exchange between the surface and the air will mostly be a result of mechanical turbulence in winter and thermal convection is very small.

3.3 One-Dimensional Modelling of the Boundary Layer Over a Motorway

For rough surfaces (which a trafficked motorway undoubtably is) in neutral conditions, the wind speed (u) can be described as a function of height Z:

$$u = \frac{1}{k}\left(\frac{\tau}{\rho}\right)^{\frac{1}{2}} \ln\left(\frac{Z - d}{Zo}\right) \quad \text{where } Z > H_r > Zo + d \qquad (3.1)$$

where k = von Karmen constant (the value of which is in dispute as will be discussed later)

τ = shear stress (the flux of horizontal momentum transferred vertically and absorbed by the ground due to molecular collision, considered a constant)

ρ = air density (considered a constant near ground)

d = zero plane displacement

Zo = roughness length

H_r = height of roughness (e.g. vehicle height)

The ratio $(\frac{\tau}{\rho})^{\frac{1}{2}}$ is known as the friction velocity u_* which represents a characteristic eddy velocity in a turbulent boundary layer. The zero plane displacement is the effective height at which the wind speed becomes zero, which for a growing crop, a forest or a line of stationary cars can be well above the surface. Oke (1978) states that 'In practice for a wide range of crops and trees the value of d is approximately given by: d = 2/3 h' (p98) where 'h' is the height of a crop or forest. For moving vehicles it is difficult to imagine a zero plane displacement, but for stationary vehicles the height would be of the order of a metre or so. The roughness length of a motorway with traffic is also difficult to envisage, but obviously the mixing effect of traffic implies a boundary layer deeper than for an untrafficked road. Therefore a value of Zo greater than one for an untrafficked road is required. Equation (3.1) can be rewritten:

$$u = \frac{u*}{k} \ln\left(\frac{Z - d}{Zo}\right) \tag{3.2}$$

The mechanical mixing caused by the roughness of the surface can be related to the thermal mixing caused by temperature differences between the top and bottom of the boundary layer, using Richardson's number. Thermal buoyancy is broken up by mechanical turbulence.

$$Ri = g\left(\frac{\partial\theta}{\partial z}\right) / Ta\left(\frac{\partial u}{\partial z}\right)^2 \tag{3.3}$$

θ = potential temperature   u = wind speed   z = height

where g = is the acceleration due to gravity;

Ta = average temperature of the air layer considered.

Near the ground, Ri may be calculated for the first few metres using the temperature gradient $\partial T/\partial z$ rather than $\partial\theta/\partial z$, especially in winter when the two are not very different. By convention Ri is positive in inversion profiles and negative in lapse conditions, being zero during neutral conditions. The range of Ri for which the wind profile equation is applicable is quite small:

$$-0.01 < Ri < 0.01$$

fortunately in winter Ri is only outside this range for short periods.

To model the fluxes of sensible heat and water vapour, further assumptions have to be made. Momentum is transferred downwards to the earth's surface as the wind passes over it. An exchange coefficient Km has been defined for the surface layer (Figure 3.1) as:

$$Km = \left(\frac{\tau}{\rho}\right) \left(\frac{\partial u}{\partial z}\right)^{-1} \text{ and has the units m}^2 \text{ sec}^{-1} \tag{3.4}$$

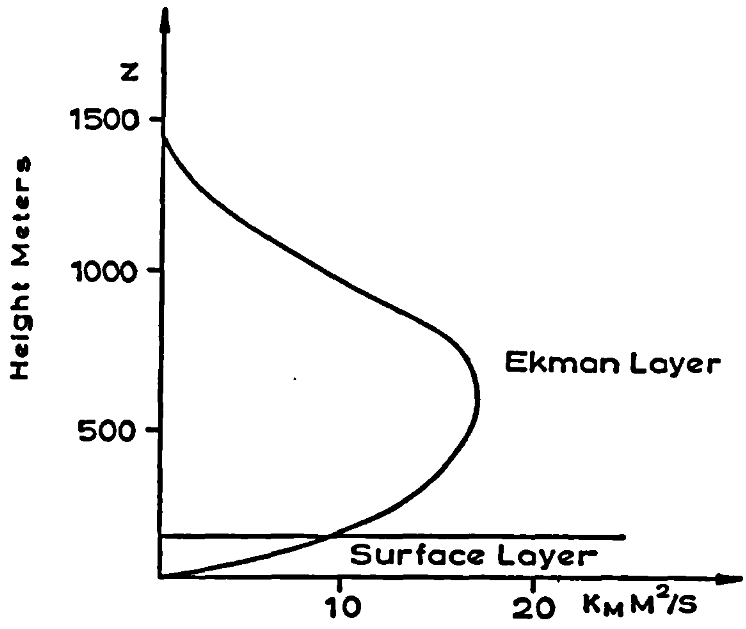
Similarly exchange coefficients for the flux of sensible heat (H) and water vapour (E) have been defined as K_H and K_V (See Rosenberg 1974)

$$\text{Therefore } \tau = \rho Km \frac{\partial u}{\partial z} \quad \text{(momentum)} \tag{3.5}$$

$$H = \rho c_p K_H \frac{\partial T}{\partial z} \text{ (heat)} \tag{3.6}$$

$$E = \text{const.} * \rho K_V \frac{\partial e}{\partial z} \tag{3.7}$$

The Reynolds analogy approach assumes that these exchange coefficients are identical in neutral conditions, so that if one is calculated the others are also known. In as far as momentum and heat are transferred by the movement of molecules this is a reasonable assumption in a moist atmosphere of air and water molecules. However, how can the value of Km be determined in non neutral conditions, and how does stability affect its relationship with K_H and K_V?



Separation of PBL into surface layer and Ekman layer showing typical K_M profile.

FIGURE 3.1

3.3.1 Flux Profiles in a Non Neutral Boundary Layer

If equation (3.2) is differentiated, the wind profile for neutral conditions becomes:

$$\frac{\partial u}{\partial z} = \frac{u*}{kz} * \frac{1}{z} \tag{3.8}$$

Monin and Obukov (1954) modified this basic equation for use in all stability conditions:

$$\frac{\partial u}{\partial z} = \frac{u*}{kz} \quad \phi m \tag{3.9}$$

where ϕm is a function of Z/L (see Dyer 1974) and L is the Obukhov scale length given by:

$$L = \frac{\rho C_p \; u*^3 \;\; TA}{Kg \;\; H} \tag{3.10}$$

Km can be related to ϕm by squaring equation (3.9) and substituting into equation (3.5):

$$Km = K^2 * Z^2 * \phi m^{-2} \;\; \frac{\partial u}{\partial z} \tag{3.11}$$

There have been many attempts to relate Ri to ϕm in the literature, most are in the form:

$$\phi m = (1 + b \; Ri)^{1/n} \tag{3.12}$$

Table 3.1 gives the most commonly used values for b and n. The variety of values for these constants is bewildering, but presumably each is appropriate to a given site where the empirical data was collected. In winter because the value of Ri rarely varies outside the range $-0.1 < Ri < 0.01$, the correction factor is usually small.

Table 3.1

Values of b and 1/n for Stability Correction

b	1/n	
10	1/2	Oke (1970)
16	1/3	Pruit, Morgan & Laurence (1973)
18	1/4	Panofsky et. al. (1960)
14-24	1/4	Sellers (1965)
36	1/2	Outcalt (1972)

The assumption that K_V and K_H are equal to K_M has been tested extensively. Generally it has been found that K_V/K_M and K_H/K_M is $\sim 1.0 \rightarrow 1.3$ in nearly neutral conditions and $0.7 \rightarrow 0.8$ in strongly stable conditions. Values can approach $2.0 \rightarrow 2.5$ in strongly unstable conditions. For modelling purposes however in winter it can be assumed that the coefficients are sufficiently equal. The choice of correction factor is one of trial and error, although the expressions yield very similar results for values of $|Ri|<0.1$.

3.3.2 Operational Forecasting

For modelling purposes even a zero dimensional model requires boundary conditions that are often difficult to provide. For instance, accurate measurements of lapse rates of moisture and air temperature are just not possible over a motorway. Measurements at one height often have to be used and certain reasonable assumptions made. Even if measurements at two heights can be made, this is not fully satisfactory as in winter many of the differences for instance in temperature between say 2 m and 10 m, are so small as to be outside the accuracy and detection of the instrument used. Measurements at the top of the atmospheric boundary layer are impossible as the boundary layer height changes daily. Various simplifications have been suggested and these will now be examined for a road surface.

3.4 Modelling the Energy Balance of a Road-Air Column

The model presented in this thesis for the prediction of road surface temperatures has been adapted from the Fortran model published by Outcalt in 1971. His digital model relied heavily upon the analogue model published by Myrup in 1969. Myrup's model was presented primarily for the examination of urban heat islands, Outcalt has broadened and developed his model for a wide variety of purposes including the examination of the energy balance of ice. Various similar models based on Myrup have emerged in North America, for example Miller et.al. (1972), but in Britain very little evidence of heat balance modelling following Myrup, other than for teaching purposes, has emerged (e.g. Unwin 1981). Blackmore (1983) presented some alterations to Outcalt's model for the prediction of road surface temperature. This thesis builds on these alterations, applying the model specifically for operational purposes.

Outcalt's model is attractive because it is simple to use and requires little computing time to produce a 24 hour surface temperature prediction. For instance the model took only seconds to run on the now replaced IBM-360 at Birmingham University. Despite the considerable alterations to the model presented in this thesis, to make it operational for the production of Road Danger Warnings, the model still only takes minutes to run on a Southwest Z-80 based microcomputer.

Miller, Johnston and Lowry (1972) have criticised Outcalt's model, and Myrup's original (1969) analogue model, presenting their own model instead. However they admit that most of their criticisms are aimed at Myrup and Outcalt has overcome most of these. Indeed as far as the heat flux in the ground is concerned they state (p77):

'....in all three models the heat flux into and out of the soil heat reservoir is the only link between time steps. Outcalt elaborates this connection in an attempt to simulate the "asymmetry produced by thermal lag" so often observed. The results from the Myrup and Outcalt models are slightly more realistic than ours.'

They conclude (p82):

'.....heat balance models such as these discussed here are more useful ..in assessing practical diagnostic questions than might at first be supposed.'

The test of any such model be it physically based or statistically based, or a mixture of both, is found in how well it simulates reality. The test of the modified form of Outcalt's model is presented in the next four chapters of this thesis.

3.4.1 Outcalt's 1971 Model

Outcalt's model is based on a simple heat balance equation at the surface:

$$\pm R_N \pm LE \pm H \pm S = 0 \qquad (3.13)$$

Where R_N = net radiation flux

LE = latent heat flux

H = sensible heat flux

S = soil heat flux

At any moment in time this equation must balance, and as each term is a function of surface temperature, there is one, and only one, surface temperature that will balance the equation. This is called the equilibrium surface temperature. Outcalt expanded the terms in equation (3.13) as follows:

(i) $R_N = (1 - \alpha)\ (Q + q) + \varepsilon_{sky}\sigma\ T_{sky}^4 - \varepsilon\sigma\ To^4$ (3.14)

Where α = surface albedo

Q = beam solar radiation

q = diffuse solar radiation

ϵ_{sky} = effective emmisivity of sky (assumed to be unity)

σ = Stefan Boltzman constant

T_{sky} = sky temperature (assumed constant when overcast or no cloud)

To = surface temperature

ε = emissivity of surface

(ii) $H = RCK\ [T2 + {}^{\Gamma}\ Z2 - To]$ (3.15)

R = stability correction factor

Where C = heat capacity of the air

K = adiabatic estimate of the turbulent transfer coefficient

$= (K^2 U_z \rho)/[\ln Z2/Zo]^2$ (Myrup 1969)

k = von Karmen's constant

U_z = wind speed at air thermal damping depth height Z2

ρ = air density

Zo = roughness length

Z2 = height of air thermal damping depth

To = temperature at Z2

Γ = dry adiabatic lapse rate

To = surface temperature

(iii) LE = RLK [q2 - qo] (3.16)

Where L = latent heat of evaporation

q2 = absolute humidity at Z2

qo = surface wetness (a function of To)

(iv) S = Ks/(Zs/2) [Th - To] (3.17)

Where Ks = thermal conductivity of soil

Zs = thermal damping depth of soil

Th = temperature depth Zs/2 in soil

To = surface temperature

$$Th\ (I) = Th\ (I-1) + [d(Ts - 2Tn(I-1) + To(I-1)/(Z2/2)^2]\ \Delta t$$

Where I = Δt, the time increment considered

d = thermal diffusivity

Ts = temperature depth Zs

With the assumptions that the sky temperature (i.e. cloud) does not change over the period considered; that the surface emissivity is constant and unity; that the surface albedo and radiation budget can be measured; that the temperature at the two boundary levels Ts and T2 can be estimated (Outcalt also made them equal); and that the surface can be determined wet or dry (or a fraction 0 $\rightarrow$ 1), the equations can be solved for To by iterative substitution.

Each of these terms in the heat balance equation will now be discussed in the light of both changes made to the original model and the justification of assumptions for a motorway surface.

3.4.2 The Heat Balance Model for Predicting Road Surface Temperatures

For the purpose of producing forecasts of road surface temperatures we have to alter the heat balance equation such that it is applicable in winter conditions for all weather situations. Thus the effect of cloud and precipitation has to be examined as well as the likely influence of advection. Each term of the heat balance equation will be examined in detail.

3.5 Net Radiation

3.5.1 Solar Radiation

The daily input of solar radiation is the driving force of the heat balance model. Wood (1978) has examined in detail the estimation of solar radiation using Outcalt's model, and has suggested several improvements to include the effect of cloud. Wood (1978) has shown that Outcalt's model contained important errors in his calculations of the diffuse and backscattering radiation. Basically, as a first approximation, the amount of scattering and absorption in the atmosphere depends on the amount of dust and water vapour in the atmosphere. Outcalt's model

---

In order to save time and space Fortran notation will be used in the rest of this chapter where appropriate. This assumes of course that the phase relationships in the heat balance model can be formulated as a set of finite difference equations capable of solution by Computer using iterative substitution as explained in Chapter 5.

incorrectly increases the amount of total solar radiation arriving at the surface when the amount of dust is increased. In Fortran notation lines 189-191 in his model should be replaced by (correction 1):

```
ABSO = -0.174*(((W*XM)/20.)**0.6)                          (3.18)
SCAT = -0.083*((D*XM)**0.9)-0.089*((XM)**0.75)             (3.19)
```

assuming standard atmospheric pressure

Where W = precipitable water in cms

XM = path length through atmosphere

D = dust factor - particles per cc

This now correctly relates absorption to the amount of water vapour present, and scattering to the amount of dust and path length (i.e. number of air molecules encountered).

The amount of dust present in the atmosphere obviously varies, but for a rural motorway it can be considered to be a constant of 0.5 particles/cc. (Alteration 1). The precipitable water (cm) has been calculated empirically for southern England by Smith (personal communication) to be (Alteration 2):

$$w = 1.5V + 0.6 \tag{3.20}$$

Where V = vapour pressure in mb.

The albedo of the surface (α) is considered by Outcalt to be a constant. Wood (1978) has shown that the empirical power law suggested by Geiger (1965) is more appropriate as the albedo obviously changes with solar angle: (Alteration 3)

$$\text{Albedo} = 0.1 + 0.131\ Z^4 \qquad (3.21)$$

Where Z is the sun's zenith angle at any particular time.

When Z = 90° ($\pi/2$ radians) i.e. at sunrise and sunset, the albedo equals $\sim$ 0.9 and when the sun is at its zenith in winter, Z = 77° and $\alpha \sim 0.5$. When the surface is wet it can be argued that the albedo should be increased, but until experiments on a motorway have been carried out it is not clear by how much. Hence the albedo is considered the same for a wet and dry road. Figure 3.2 relates equation 3.21 to Geiger (1965, p.17).

3.5.2 The Effect of Cloud

Any operational model must include the effect of cloud if it is to be of any use in Britain. Outcalt's model does not include a cloud factor. Wood (1978) has introduced two factors to reduce the solar beam in the presence of cloud. The first considers the cloud top albedo (ALBED) which directly affects the beam radiation, and the second (DPLUS) increases the diffuse radiation for broken medium cloud due to reflection from the cloud sides.

ALBED varies from zero for a cloudless sky to unity for an overcast sky and is used in the equation to calculate the total direct solar radiation reaching the surface (BEAM)

$$\text{BEAM} = (1 - \text{ALBED})*\text{EXT}*e^{(\text{ABSD} + \text{SCAT})} \qquad (3.22)$$

(Alteration 4)

Where EXT = extraterrestial radiation arriving at the outer edge of the atmosphere

ABSD = given by equation (3.18)

SCAT = given by equation (3.19)

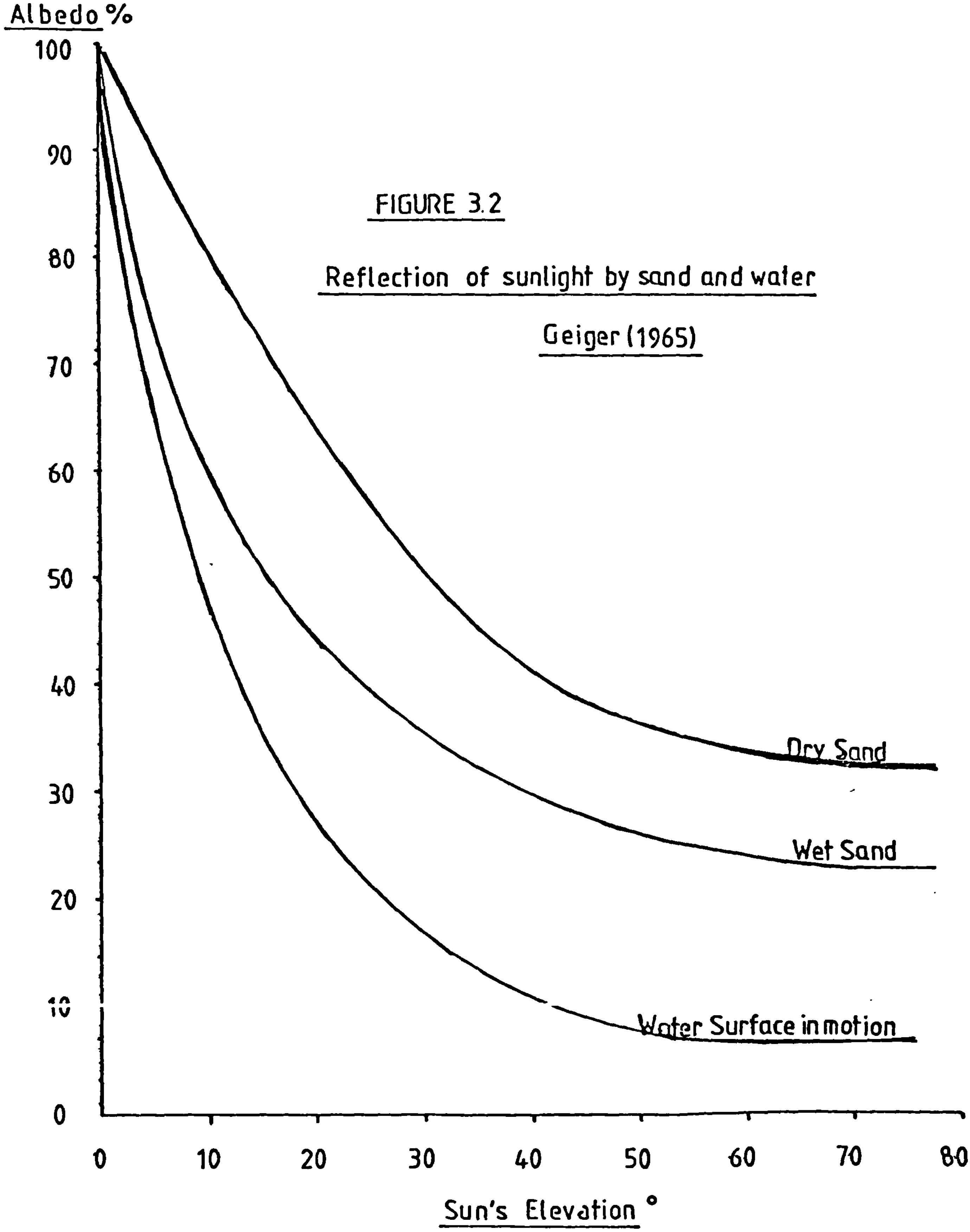


FIGURE 3.2

Reflection of sunlight by sand and water

Geiger (1965)

DPLUS varies between 0.5 for a cloudless sky and 1.3 for 5/8 to 6/8 cover of cumiliform clouds. The amount of diffuse radiation arriving at the surface is given by (Alteration 5):

$$DIFF = DPLUS*EXT* (1 - e^{SCAT}) \quad (3.23)$$

The values of DPLUS and ALBED for differing cloud amounts and types are given in Table 3.2 taken from Wood (1978).

This table assumes that forecast values of cloud cover will not be accurate to one okta or one cloud type. Hence groups of cloud types and amounts have been used. The table has therefore, to be used with due caution particularly when there is more than one cloud layer present. Wood (1978) found a good agreement between the modelled and actual values using measurements of cloud amount and type, and direct and diffuse solar radiation, taken at the London Weather Centre.

3.5.3 Outgoing Terrestial Radiation

Just as incoming solar beam is impaired by cloud, so the cloud reduces effective long wave radiation loss by the surface. A factor KCLOUD which was used by Thornes (1972) has been adapted such that the net radiation RN is given by:

$$RN = (1 - ALBEDO) * SUN - RNLONG* KCLOUD \quad (3.24)$$

(Alteration 6)

Where RN = net radiation

ALBEDO = surface albedo as given in equation (3.21)

SUN = total solar radiation arriving at the surface

SUN = BEAM + DIFFUSE + BACKSCATTERING

Table 3.2 Cloud Factors ALBED and DPLUS for Differing Cloud Types and Amounts

	CLOUDLESS	1-2 OKTAS			3-5 OKTAS			6-7 OKTAS			OVERCAST
		LOW	MED	HIGH	LOW	MED	HIGH	LOW	MED	HIGH	
ALBED	0.0	0.2	0.1	0.05	0.5	0.3	0.1	0.9	0.9	0.3	1.0
DPLUS	0.5	0.6	0.6	0.5	0.8	0.8	0.5	1.0	1.3	0.6	1.0

LOW = Cu, CN, Ns St, Sc

MED = Ac, As

HIGH = Ci, Cs, Cm

Beam is given by equation (3.22)

Diffuse is given by equation (3.23)

BACKSKT = 0.5 * ALBEDO * (BEAM + DIFF) * (1 - exp(SCAT)) (3.25)

RNLONG = effective outgoing long wave radiation

The calculation of RNLONG has been changed from Outcalt's use of the sky temperature (which is difficult to measure), to a form of Angström's equation, as used in Thornes (1972):

$$\text{RNLONG} = I_o\uparrow - I\downarrow = I\uparrow$$

$$= \varepsilon\sigma\, T_o^4 - (\sigma\, T_A^4(0.82 - 0.25 \times (10^{-0.094e}))) \qquad (3.26)$$

(Alteration 7)

Where $I\uparrow$ = the effective outgoing terrestial radiation

$I_o\uparrow$ = the total terrestial radiation emitted by the surface

$I\downarrow$ = the return long wave radiation from the air

(Alteration 8) ε = emissivity of the motorway surface (taken to be 0.95)

T_o = surface temperature

σ = Stefans constant

T_A = air temperature at 2 m

e = vapour pressure (mb) at 2m

Angström's original equation for effective outgoing radiation was based on screen air temperature measurements exclusively. Equation (3.26) is thus adapted to use actual surface temperatures as well as the air temperature measured at 2 metres. The effect of cloud is modelled by multiplying RNLONG by a cloud factor KCLOUD. Table 3.3 gives the KCLOUD values used for differing cloud types.

Table 3.3 KCLOUD Values for Differing Cloud Types and Amounts

	CLOUDLESS	1-2 OKTAS			3-5 OKTAS			6-8 OKTAS		
		LOW	MED	HIGH	LOW	MED	HIGH	LOW	MED	HIGH
KCLOUD	1.0	0.87	0.91	0.96	0.58	0.72	0.86	0.32	0.54	0.78

Such empirical fornulae as given in equations (3.24) and (3.26) must be treated with caution, for as Monteith (1975) states:

'For prediction, they are most accurate under average conditions, e.g. when the air temperature does not increase or decrease rapidly with height near the surface and when the air is not unusually dry or humid.' (p.37)

In winter in Britain the weather conditions can be assumed to be within this average group.

3.6 The Sensible Heat Flux

The exchange of heat between the surface and the air (H) as given by Outcalt (equation (3.15)) can be expanded to give the following expression for H, including the stability correction factor called RIFIX:

$$H = \frac{(k^2 \ \rho U_Z)}{(\ln \frac{ZA}{Z0})2} \ * \ (1 - 18 \ Ri)^{1/4} \ * \ Cp \ * \ (TA_Z + \Gamma \ ZA - To) \quad (3.27)$$

in Fortran H = EXCO * RIFIX * AIRCAP * (TA + DRYADB * ZA - To)

Where EXCO = exchange coefficient

RIFIX = the stability correction factor

Cp = specific heat of air at constant pressure

TA_Z = air temperature at boundary layer top (Z_z)

Γ = D.A.L.R.

To = surface temperature

k = von Karmen's constant

ρ = air density

U_Z = wind speed at boundary layer top (Z_z)

Zo = roughness length

Ri = Richardson's number

The only factors that we can be confident in assigning a value to are ρ and Cp which have the values $\rho = 0.001$ g/cm^3 and $Cp = 0.25$ cal/g/deg.. All the other terms have to be justified in terms of the assumptions made for a motorway surface. Von Karmen's so called constant is the subject of current debate as to whether its value is 0.4 or 0.35 (Table 3.4). As H is in direct proportion to k^2 the difference is significant as $(0.35)^2 = 0.1225$ and $(0.4)^2 = 0.16$. Hence a value of k of 0.4 gives approximately $(\frac{0.16 - 0.1225}{0.1225} \times 100)$ 30% more H than a value of 0.35.

Table 3.4 Von Karmen's Constant as Proposed in the Literature

		k
Monteith	1975	0.41
Rosenburg	1974	0.4
Sellers	1965	0.4
Oke	1978	0.4
Outcalt	1971	0.4
Budyko	1974	0.38 - 0.4
Businger et.al.	1971	0.35
Nystem	1980	0.35

Businger et.al. (1971) have shown that a value of k = 0.35 suited their observations better than a value of 0.4. Also they suggest that the assumption that KM = KH is not valid. They suggest, from extensive observations, that KH = 1.35 KM. Thus the exchange coefficient in equation (3.27) would have to be multiplied by 1.35. It is no surprise to find that $(0.35) \times 1.35 \approx (0.4)^2$. Hence previous assumptions of k = 0.4 and KH = KM give the same results. In this analysis k is left at 0.4 and KM is assumed to equal KH and KV, although if future evidence confirms that k = 0.35 and that KH = 1.35 KN then the model can be adjusted without any difference to the results.

U_Z is the wind speed at the top of the boundary layer of height Z. In view of the fact that this height is likely to vary day by day a height of 20 m has been chosen to simplify the analysis. Wind was measured at 2 m on the M4 site and hence the wind speed at 20 m has been calculated from the expression:

$$U_{20} = U_2 * \frac{\ln\ (20/0.15)}{\ln\ (2/0.15)} = 1.89\ U_2 \qquad (3.28)$$

where 0.15 is the assumed roughness length (Zo) of the motorway. Two assumptions have to be explained here, firstly the choice of 20 m for the boundary layer height and secondly the choice of Zo = 0.15 m = 15 cm for the roughness length.

Outcalt (1971) introduced the idea of an atmospheric damping depth Z_2 that corresponds to the height at which the thermal diffusivity, which increases with height, becomes greater than the bulk adiabatic diffusivity which decreases with height:

$$\text{i.e. where } \frac{Z_2{}^2}{12t} > k^2 U_{Z^2} / \ln(Z_2/Zo) \qquad (3.29)$$

Outcalt admits that this is a crude approximation but justifies its use in that it takes into account the wind speed and surface roughness to give a damping height of between 10-25 m for a wind velocity of 1 m/sec., as roughness is increased from 2 cm → 500 cm. In practice, there is a problem with this concept as the damping depth is a function of the windspeed. In other words, if the wind is measured at a particular height how can the wind at the damping depth be estimated if U_Z is not known? Catch-22! Hence a level has to be chosen so that U_2 and then the damping depth can be calculated . Myrup (1969) used a constant level of 300 m which is much too high for winter conditions. Hence a level of 20 m has been chosen for the estimation of U_{20} from U_2, and this gives damping depth heights of between 11 m and 30 m for windspeeds 1 → 10 as shown in Figure 3.3.

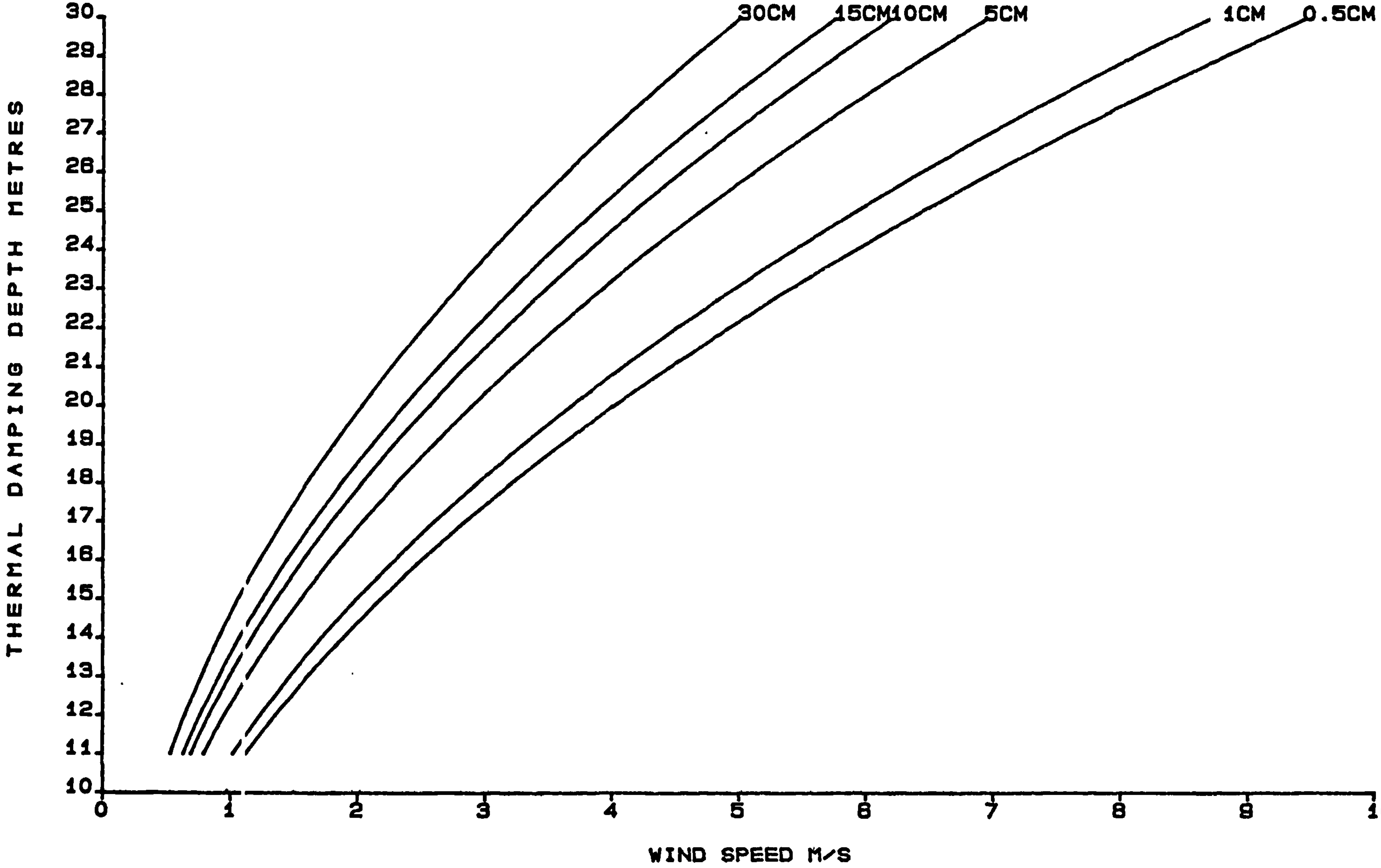
A roughness length of 15 cm (Alteration 10) has been chosen to give a sufficient damping depth for a trafficked motorway. Other estimates of Zo for roads have assumed that there is no traffic. Table 3.5 gives some typical values from the literature.

Table 3.5 Value of Roughness Length Zo from the Literature for Roads

		Zo cm
Nystem	1980	0.5
Greene	1980	6.0

If the wind is blowing down a traffic free motorway a roughness length of less than a centimetre might be considered. However the continuous presence of traffic suggests that a value more appropriate to an urban environment should be used. Lettau (1969) suggested an approximation of Zo as a function of the average height of obstructions and the silhouette ratio. Oke (1978) gives typical values between 5 cm and 70 cm for urban areas outside the central business district. A value of 15 cm therefore seems appropriate for a motorway (Thornes 1983a).

FIGURE 3.3 THERMAL DAMPING DEPTH VERSUS WIND SPEED VERSUS ROUGHNESS LENGTH



It could be argued that a different value of Zo should be used according to wind direction - but further experimentation is required. Basically, the greater the value of Zo used the greater the value of H calculated.

The next expression in equation (3.27) to be explained, is the stability correction factor RIFIX. Outcalt uses the expression RIFIX = $(1-32\ \mathrm{RI})^{\frac{1}{2}}$ such that if Ri is negative (i.e. unstable condition) the expression RIFIX is greater than unity and H is increased. Conversely, if Ri is positive (i.e. stable condition) RIFIX is less than unity and H is reduced. As shown earlier this correction factor is usually written in the form:

$$\phi = (|1 + b\ \mathrm{Ri}|)^{1/n} \qquad \text{(equation 3.12)}$$

Greene (1980) in modifying Outcalt's model used the expression RIFIX = $(1 - 18\ \mathrm{Ri})^{1/4}$, and many other values have been proposed as discussed earlier and shown in Table 3.1. Outcalt (1971) justified the value for b of -32 as follows:

'In limited tests the value of (-32) most suitably simulated the field data as it lowered the equilibrium surface temperature during extreme lapse conditions and raised the night minimum temperature.' (p382)

Table 3.6 Typical Values of Richardson's Number in Winter

If Ri = 0.01 then $(1-32\ \mathrm{Ri})^{1/2} = 0.824$

and $(1-18\ \mathrm{Ri})^{1/4} = 0.95$

If Ri = - 0.01 then $(1-32\ \mathrm{Ri})^{1/2} = 1.15$

and $(1-18\ \mathrm{Ri})^{1/4} = 1.04$

Outcalt does not state with what he is comparing his value as it is well outside the range of values quoted by other authors. The expression used by Greene has therefore been adopted: RIFIX = $(|1-18\ \mathrm{Ri}|)^{1/4}$ (Alteration 11) which is the expression used by Panofsky et.al. (1960) and is thus within the range given by Sellers (1965). In winter, of course, the values of RIFIX are close to unity as shown in Table 3.6. In a more recent paper Dozier and Outcalt (1979) have replaced the Richardson number correction to use the Businger-Dyer functions for turbulent heat and water vapour transfer as described by Paulson (1970). This approach makes very little difference in winter.

The final expression in the equation (3.27) relates the potential air temperature to the surface temperature: ($TA_Z + \Gamma\ ZA - To$). This determines the sign of the expression for H. If the ground To is warmer than the air then H is negative and vice versa. TA_Z the air temperature at the boundary layer top Z_2 is impossible to measure for the same reason as for the wind speed. Outcalt used a constant air temperature at this height to close his model, and assumed that TA_Z = TH i.e. that the temperature at the thermal damping in the ground is equal to the temperature at TA. This assumes that the temperature will change little during 24 hours at height Z_2. This is a reasonable assumption in winter but because air temperature is measured normally at 2 m on motorway sites it is necessary to use average air temperatures at 2 m instead of a (Alteration 12) guessed value for TA_Z. The difference in temperature between 2 m and 20 m (the height at which the wind speed was adjusted to) is very small in neutral conditions, as the D.A.L.R. is 1°C per 100 m, so the temperature difference is only about 0.18°C which can be ignored. Obviously, for real time forecasting purposes it would be simplest to be able to feed into the model a single constant value of TA for the next 24 hours. More research needs to be carried out before this is possible. In the absence of advection it might be possible to calculate a value of TA that would correctly balance the heat balance equation for the previous day, and carry that value forward.

If we feed in typical values for the calculation of H we can see the relative importance of each term.

Consider H = EXCO * RIFIX * AIRCAP * (TA-To)

If EXCO = 0.00321 (wind = 5.6 m/s)

RIFIX = 0.95

AIRCAP = 0.24

TA - To = 1.5°k

then H = 1.098×10^{-3} langleys sec^{-1} = 65.8 millilangleys min^{-1}

if TA - To = 3°k = 132.0 millilangleys min^{-1}

Thus H is determined primarily by the temperature difference: (TA - To), the difference between the road and air temperature.

3.7 The Latent Heat Flux

As a simplifying assumption, the motorway surface is considered impervious and either wet or dry. Three rainfall types are considered that trigger the term SRHF, which equals zero if the road is dry and unity if the road is wet. It is related to the latent heat flux as:

LE = EXCO * RIFIX * LHEAT * QGRAD * SRHF (3.30)

The model is adjusted (Alteration 13) so that if rain is forecast for a particular time, SRHF can be set equal to unity at that time. The rate at which the road dries out is of particular importance for ice prediction. The quantity of water that remains on a road surface after rain is related to the type of road surface, the camber, the slope, the amount of traffic and the rate of evaporation. For the purpose of this study three rainfall rates have been defined: heavy, medium and light. These are subjective amounts that roughly translate into continuous rain, heavy showers and light showers. It is assumed that approximately 1 mm of rain is stored on the road after heavy rain (a figure of 1.2 mm is given by williamson 1969), 0.5 mm after medium precipitation and 0.25 mm after light precipitation (Alteration 14). Neglecting traffic for the moment the amount of heat required to evaporate 1 mm of water from 1 cm^2 of road is:

$$Q = M \times L = 0.1 \times 509 = 59 \text{ calories}$$

The latent heat flux is calculated every 20 minutes in the model and hence if this term is summed, the time when the road dries out can be calculated. This time is when $\Sigma LE \times 20\ m = 59$ or when $\Sigma LE = \frac{59}{20} \approx$ 3 cals $\equiv$ 3,000 millilangleys. Therefore when the sum of LE reaches 3,000, SRHF is set at zero. For medium and light rain the thresholds are 1,500 and 750 respectively. The effect of traffic obviously will speed up the rate of drying via splashing, however the thresholds do give reasonable estimates as will be shown in the results section.

The only term in equation (3.30) not yet explained is QGRAD which represents the specific humidity gradient:

$$QGRAD = \left(\frac{0.622 + SHMB(TA) * RHF}{1013}\right) - \left(\frac{0.622 \times SHMB(To)}{1013}\right) \quad (3.31)$$

where SHMB = the saturated vapour pressure

and RHF = relative humidity fraction.

Effectively QGRAD is comparing the vapour pressure at 2 m where TA and RHF are measured with the saturated vapour pressure over the wet surface which has temperature To. Normally when evaporation is taking place QGRAD is negative. If QGRAD is positive however dew is formed. If the surface is wet and the surface temperature falls below zero centigrade thenthe water is assumed to turn to ice, and the latent heat released is used to offset the cooling of the road. The term LM has been introduced such that:

$$LM = a(1 - \Sigma LE/RAIN) \qquad \text{(Alteration 15)}$$

where a = constant

RAIN = 3000, 1500 or 750 according to precipitation rate chosen

To estimate the constant "a" consider the amount of latent heat released when 1 mm of water freezes:

$$Q = M \times L_{Fusion} = 0.1 \times 80 = 8 \text{ calories}$$

This is released over several hours to both offset the cooling of the road and the air. If half of this is considered to be given up to the road and it takes 1 hour to freeze then the value of LM per minute $= \frac{4000}{60} \simeq 67$ millilangleys

Hence, as a first approximation "a" has been set equal to 70. A corresponding value for the melting of ice has not been included in the model as we are interested primarily at this stage in ice formation. If salt is spread on the motorway then LM is set equal to zero, hence because of the large amounts of salt used on motorways LM is rarely used.

The formation of hoar frost on the road is modelled in a similar fashion to the formation of dew, only the latent heat of sublimation rather than the latent heat of vapourisation is used such that:

LE = EXCO * RIFIX * LHSUB * QGRAD (Alteration 16)

where QGRAD is positive and To < 0.0°C.

Hoar frost is not usually considered a serious hazard on motorways, however when compacted by traffic it can turn to ice (Thornes 1973). The actual quantity of hoar frost formed on roads has never to my knowledge been examined quantitatively, and more research is required to decided whether or not to salt the motorway if hoar frost is forecast by the model.

3.8 The Road Heat Flux

The thermal damping depth in a road obviously depends upon the materials of which it is composed. The M4 motorway where the instruments were installed to test the model comprises a composite roadbase made up of 80 mm dense bitumen macadam laid on 180 mm of lean concrete, 60 mm of dense bitumen macadam basecourse, and a 40 mm thick rolled asphalt wearing course with coated granite chippings as shown in Figure 3.4. Table 3.7 shows the thermal properties of the concrete and bitumen macadam used.

Outcalt (1971) assumed that the temperature at the damping depth of the ground equalled the temperature of the damping depth in the atmosphere. He made no attempt to measure temperatures at depth in the ground. Consequently he had to run his model for 24 hours to set up the temperature lags in the ground before he started to run the model for

FIGURE 3.4 Comparison of sub-road structure with depths used in heat flux calculations

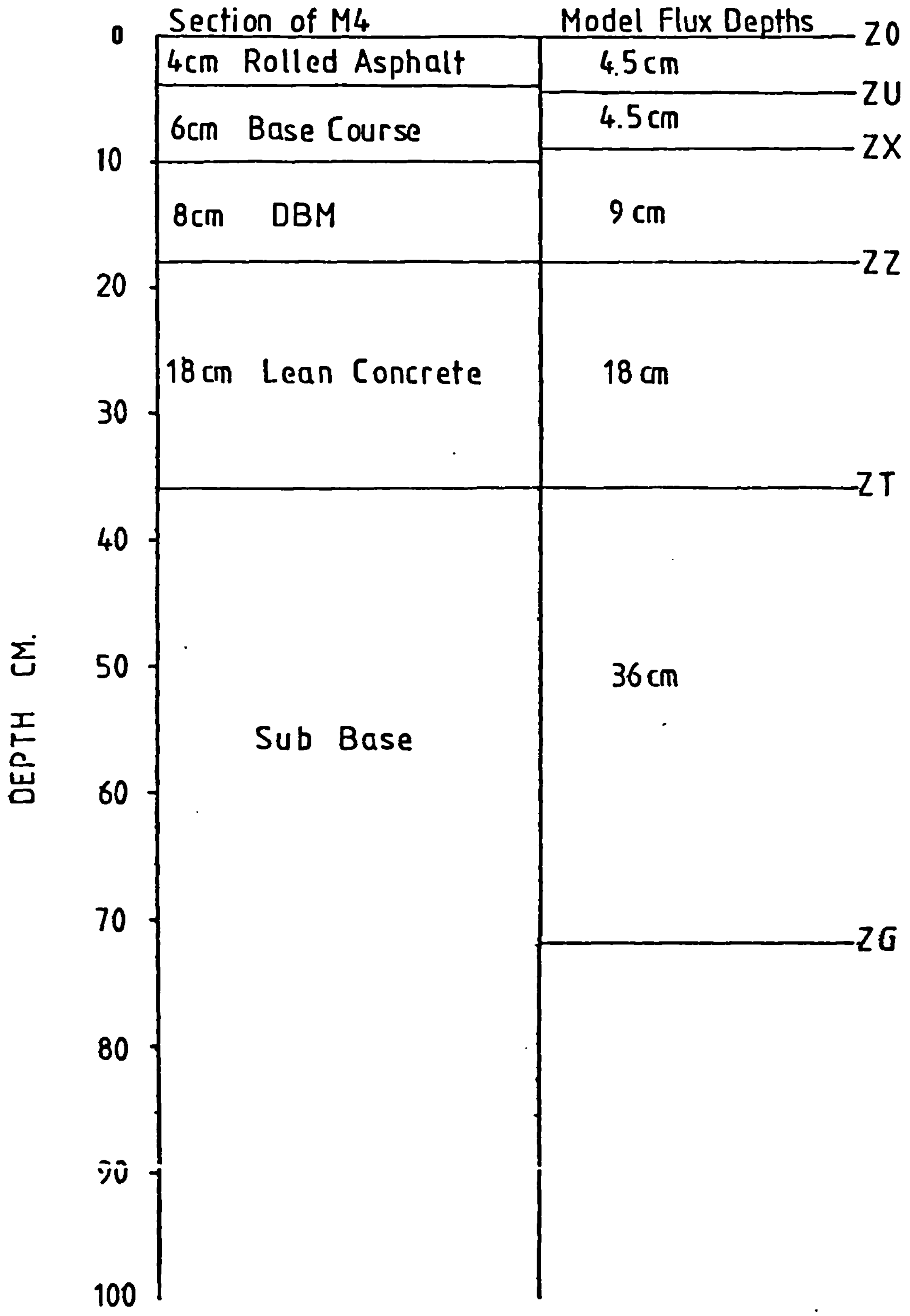


Table 3.7 Thermal Properties of Lean Concrete and Bitumen Macadam on M4 Motorway (Greening (1970), Wilson (1976))

Road Type	Thermal Diffusivity	Thermal Conductivity	Damping Depth
Concrete	1.2×10^{-2} $cm^2 sec^{-1}$	4.8×10^{-3} cal $cm^{-2} sec^{-1}$	79 cm
Asphalt (DBM)	0.7×10^{-2} $cm^2 sec^{-1}$	3.1×10^{-3} cal $cm^{-2} sec^{-1}$	60 cm

predictive purposes. This is time consuming and not very accurate if the temperatures at depth have to be guessed. This was avoided on the M4 as temperatures at 36 and 18 cm (Alteration 17) below the road were measured. The temperature at 36 cm has been taken to be the temperature half way between the surface and the damping depth at 72 cm.

This value of 72 cm for the damping depth is reasonable as it lies between the damping depths for asphalt and concrete as shown in Table 3.7. The values given in 3.7 are estimates from the literature and not measured values. It is hoped in future to get actual values for the different motorway layers. The thermal conductivity of the sub-base is assumed to be the same for that of concrete. The heat fluxes for each layer are then calculated and S is calculated from equation (3.33). The equation for the heat fluxes in each layer are shown in the Fortran programme in Appendix 1. Basically the heat flow is described by the one-dimensional conduction equation such that at depth ZU:

$$\frac{\partial Tu}{\partial t} = RD * (To - (2*Tu + TX)/ZU^2) \qquad (3.32)$$

where RD = thermal diffusivity

TX = temperature at depth (2 x ZU)

The heat flux is calculated as follows:

$$S = (RK * ZU) * (TU - To) \qquad (3.33)$$

where RK = thermal conductivity

ZU = is the depth 4.5 cm as shown in Figure 3.4

TU = temperature at depth ZU

3.9 Summary

Many assumptions have been incorporated into the heat balance model proposed in this chapter. The only way to discover whether or not they are justifiable is to test the model against observed road surface temperatures. This is carried out retrospectively in the next three chapters. Table 3.8 gives a summary of all the corrections and alterations to Outcalt's original model.

Table 3.8

Correction to Outcalt's Model

1. ABSD = -0.174 x (((W * XM)/20.)** 0.6)
2. SCAT = -0.083 x ((D * XM)**0.9) - 0.089 * ((XN)**0.75))

Alteration to Outcalt's Model

1. D is constant = 0.5 particles/cc
2. Precip. water = 1.5V + 0.6
3. Albedo = 0.1 + 0.131 Z^4
4. ALBED defined
5. DPLUS defined
6. KCLOUD defined
7. RNLONG calculated using Angstrom's equation
8. Use of emissivity ε = 0.95
9. Use of UZ at Z = 20 m
10. Roughness length Zo = 15 cm for a road
11. RIFIX = $(1 - 18\ \mathrm{Ri})^{1/4}$
12. Using TA at 2 m instead of at 20 m or Z
13. Forecasting road to become wet at a particular time
14. Three rates of rainfall
15. Definition of LM
16. Formation of hoar frost on road
17. Use of actual temperatures at 18 and 36 cm

CHAPTER 4 INSTRUMENTATION OF THE M4 MOTORWAY

4.1 Introduction

Hay and Young (1972) were the first in Britain to propose that road surface temperatures and wetness could be automatically measured, using the then little developed idea of a microprocessor - modem link, to transmit real time data to the Transport and Road Research Laboratory. Much of the equipment for this project was purchased but at short notice the direction of the research was changed from ice prediction to fog prediction. The site on the M4 motorway near Theale, 65 km west of London, (Figure 4.1) was chosen because of its proximity to several flooded gravel pits which it was thought could lead to localised fog formation. This research was completed in 1978 (Jeffery and White 1981) and the microprocessor modem link that had been used to collect the fog data, became available again for ice prediction. However, the equipment had to be extensively modified to cope with an array of new instruments. The only instruments that were still useful were those measuring wind speed and air temperature mounted on an 'X-mas' tree (the white construction as shown in Figure 4.2) in a fenced compound at the side of the motorway. Figures 4.2 also shows the dimensions of the compound to the road's north. The sky view factor for the site has not been calculated but is close to unity. This has not been included directly in the modelling discussed in Chapters 3 and 5.

4.2 Instrumentation

Although the microprocessor transmitted data back to the Transport and Road Research Laboratory once an hour, the method of data storage on paper tape meant that "real time" data analysis was not possible.

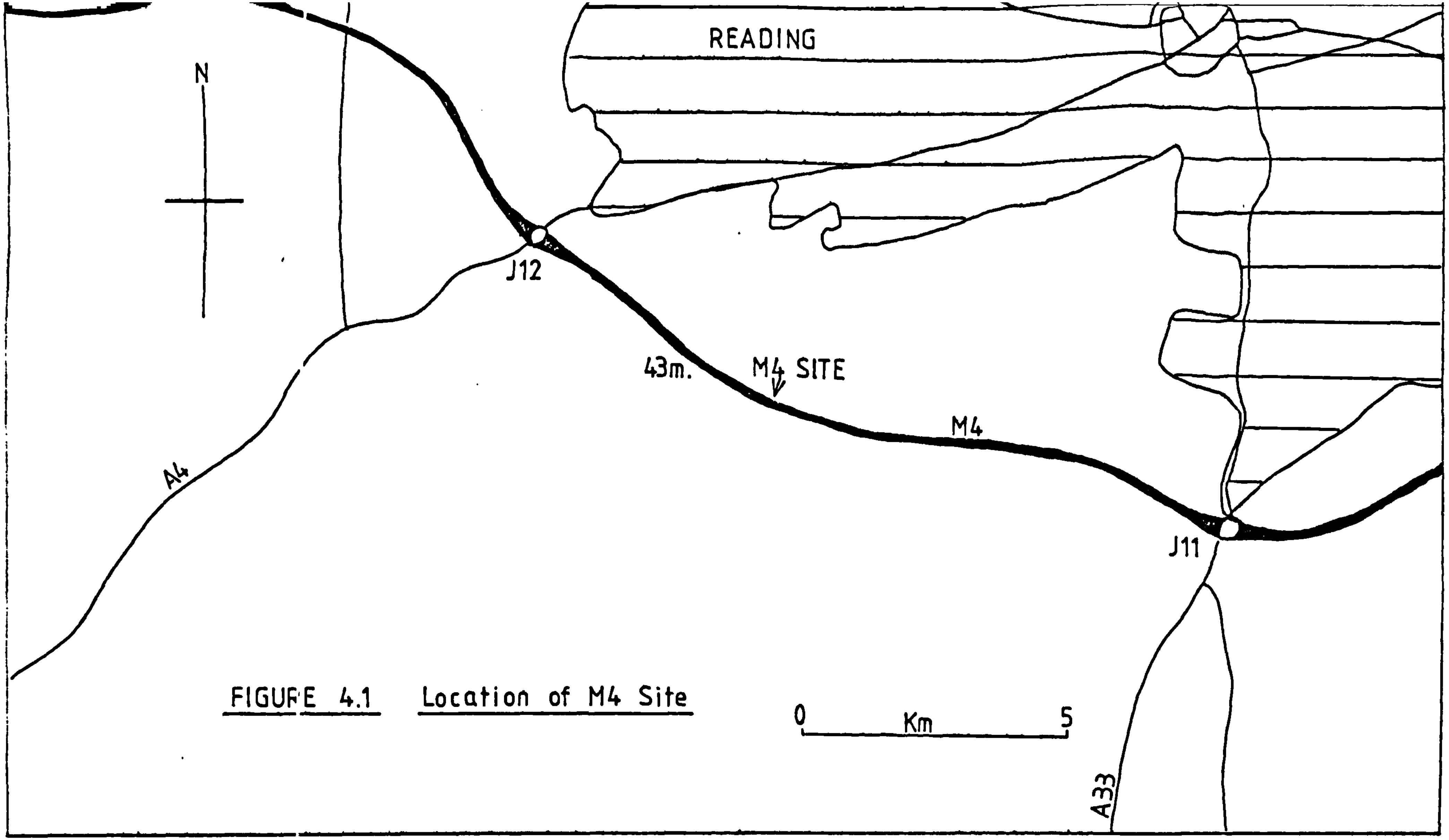


FIGURE 4.1 Location of M4 Site

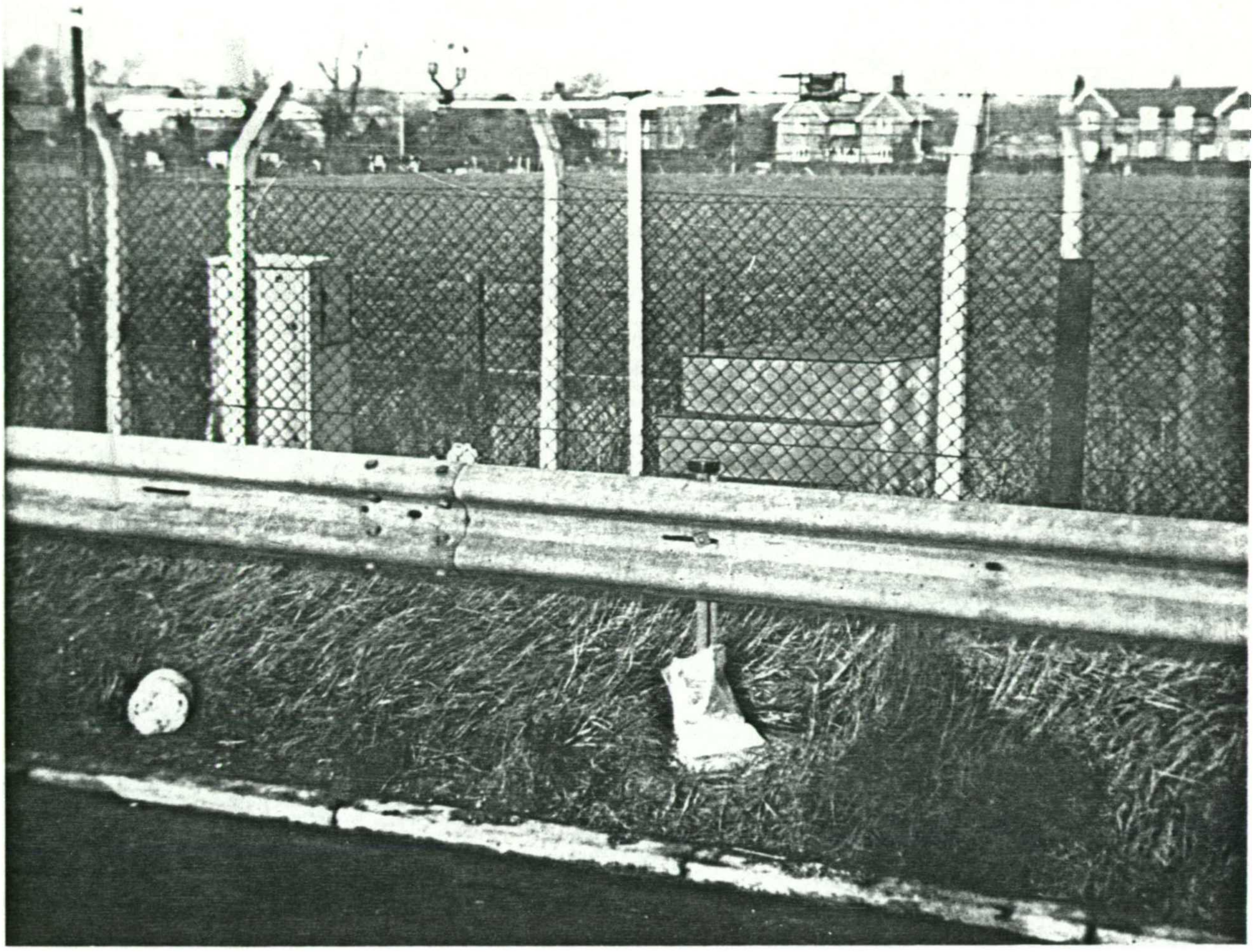
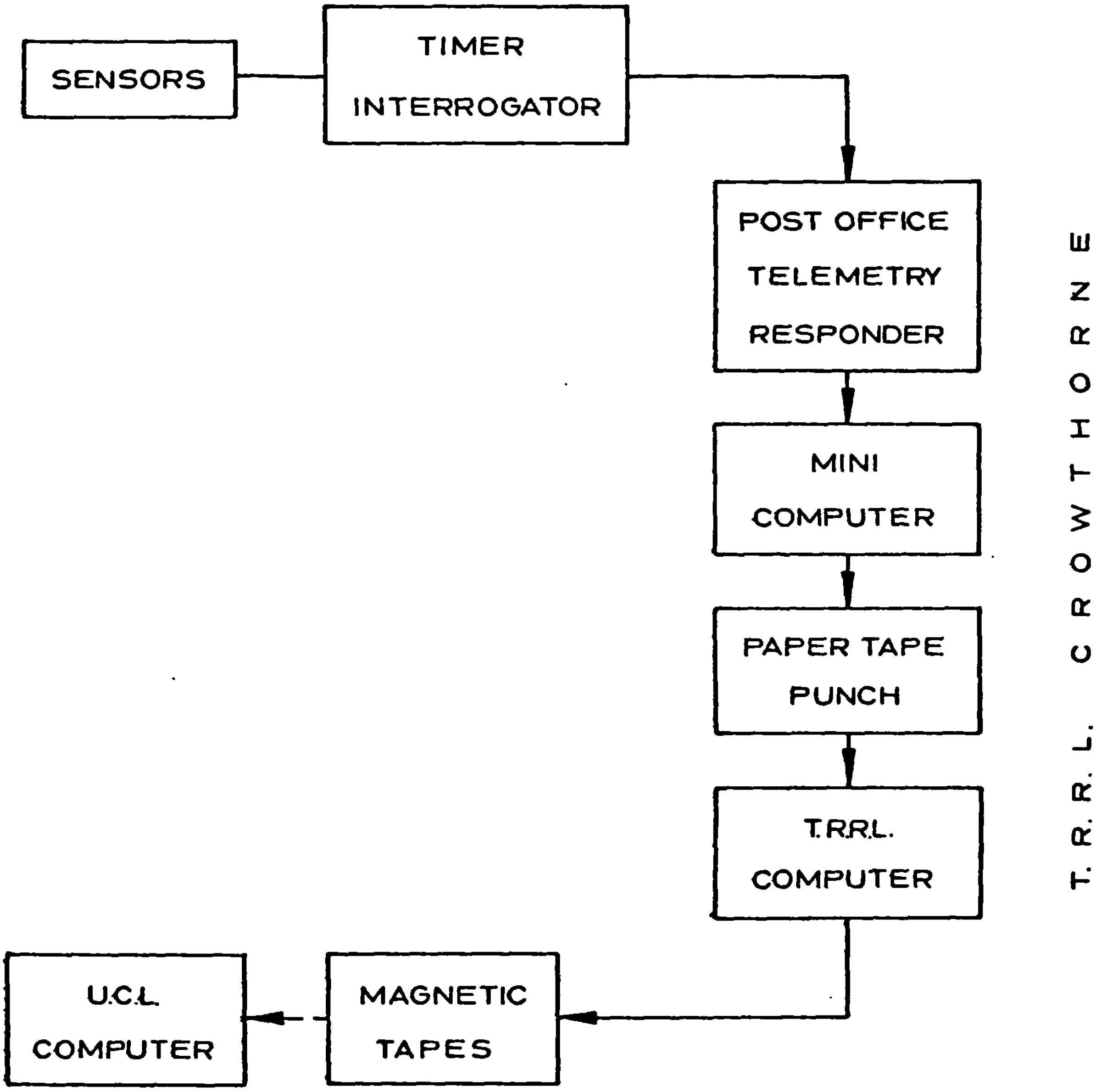


FIGURE 4.2 The M4 Compound with 'xmas tree' of instruments

The compound was thought necessary by the Department of Transport to prevent vandalism. It had minimal effect on the observations made within it.

M4 THEALE



University College, London

Sequence of data collection from the M4 to Un iversity College London

FIGURE 4.3

Table 4.1 Instruments at the M4 Site

A. In the Road

(i) 2 thermistors just below the surface out of the wheel tracks in the slow lane at 0.5 cm

2 thermistors at 18 cm

2 thermistors at 36 cm

(ii) A surface wetness meter

B. In the Slab

(i) 2 thermistors just below the surface at 0.5 cm

2 thermistors at 18 cm

2 thermistors at 36 cm

(ii) A surface wetness meter

C. On the X-mas Tree

1 resistance thermometer for air temperature at 2 m

1 wind speed (portan anenometer) at 2 m

NOTES:

(i) Net radiation was measured with a middleton net radiometer but the results were found to be unreliable unless the instrument was checked every day which was impossible.

(ii) A wet bulb resistance thermometer was not used as it gave unreliable results.

(iii) Similarly the wind direction indicator did not function reliably.

In reality it took up to a month to get the data back to London in a usable form, as shown in Figure 4.3. Table 4.1 lists all the instruments that were installed during the early winter of 1978. In order to compare the temperature and wetness of an untrafficked and unsalted road, with the motorway, a slab of identical structure to the motorway was installed within the compound. The slab is 2 m x 2m and weighs 6 tonnes, being constructed of an 18 cm dense bituminous macadam layer with granite chips (a typical B5594 wearing course) laid over 18 cm of concrete. The slab was hoisted into the compound by crane and rested on the surface (see Figure 4.11).

In order to install the wetness meter and thermistors, the motorway slow lane had to be coned off, and three circular holes diamond drilled into the carriageway (Figure 4.4). This procedure took a whole day including cutting slots in the road to take the wiring back to a 'Plessey' box in the compound. Underground cabling then carried the signals to a microprocessor based in a hut 500 metres away. The cabling involved was considerable and it took a month and a half (including Christmas) to complete after the initial instalation of the sensors.

4.2.1 Temperature

The air temperature was measured with a resistance thermometer (double shielded by white metal plates) to an accuracy of ± 0.1°C. The instrument was interrogated every 20 minutes. The "X-mas" tree is sited approximately ten metres to the north of the motorway, and hence wind direction determines whether or not the air temperatures recorded are affected by the air first passing over the motorway. Table 4.2 confirms that this is so. Winds with a northerly component, such that the air reaches the "X-mas" tree before the motorway, give a bigger

Table 4.2 Wind Direction and the Maximum Difference Between Road and Air Temperature

Wind Direction v. T_{max} Road-Air when Road-Air max > 3°C

Date	Max T_{R-A}	Wind Direc. at Noon
02-03F79	3.7	North East
25-26F80	4.3	East
03-04F80	7.0	Anticyc. over site
04-05M80	6.3	Anticyc. over site
08-09M80	4.9	North
09-10M80	6.9	North
10-11M80	4.3	North West
20-21M80	9.2	East
21-22M80	7.0	East
22-23M80	7.8	South
01-02A80	4.4	Slack
02-03A80	7.5	North West
03-04A80	10.5	North

Wind Direction v. Days When Road-Air max < 2.0°C

01-02F79	-1.0	South West
06-07F79	1.5	South East
07-08F79	0.5	South
11-12F79	0.8	South East
12-13F79	0.1	South East
22-23F80	1.0	South
24-25F80	1.6	South East
06-07M80	-0.7	South West
07-08M80	1.5	South West

difference between the air and road maximum temperatures than winds with a southerly component.

The road and slab temperatures were measured with thermistors which were waterproofed with vinyl tips and leads, accurate to ± 0.1°C. Two cores were diamond drilled from the road to a depth of 36 cm, and replaced with cores of identical construction with thermistors placed at 0.5, 18 and 36 cm (see Figures 4.4 and 4.5). The cores were sealed in place with blackened epoxy resin and warm pitch. A similar core was placed in the slab. The two sensors at 0.5 cm in the road were as close to the surface as is practically possible on a heavily trafficked motorway. The two sensors gave almost identical readings (see Figure 4.6) which were averaged to give an estimate of the road surface temperature. The thermistors at 0.5 and 18 cm were iterrogated every 10 minutes, whilst those at 36 cm were interrogated every 20 minutes. The temperature differences between thermistors at similar depths were normally found to be less than 0.1°C.

The wet bulb resistance thermometer did not give reliable results, in that the sitewas only visited once a week and the reservoir of distilled water dried out in that time. Therefore, the humidity for the site has had to be estimated from observations at RAF Benson 20 km to the north. Other methods of automatically measuring humidity without a wet bulb thermomenter are available (and are now being used in the West Midlands) but they were not available for the M4 site.

4.2.2 Wind

A Porton anenometer was used to measure wind speed. It was mounted on a boom opposite the air temperature recorder at a height of 2 m.

FIGURE 4.4 The instrumented cores in the slow lane of the M4 motorway

FIGURE 4.5
The instrumented cores before installation

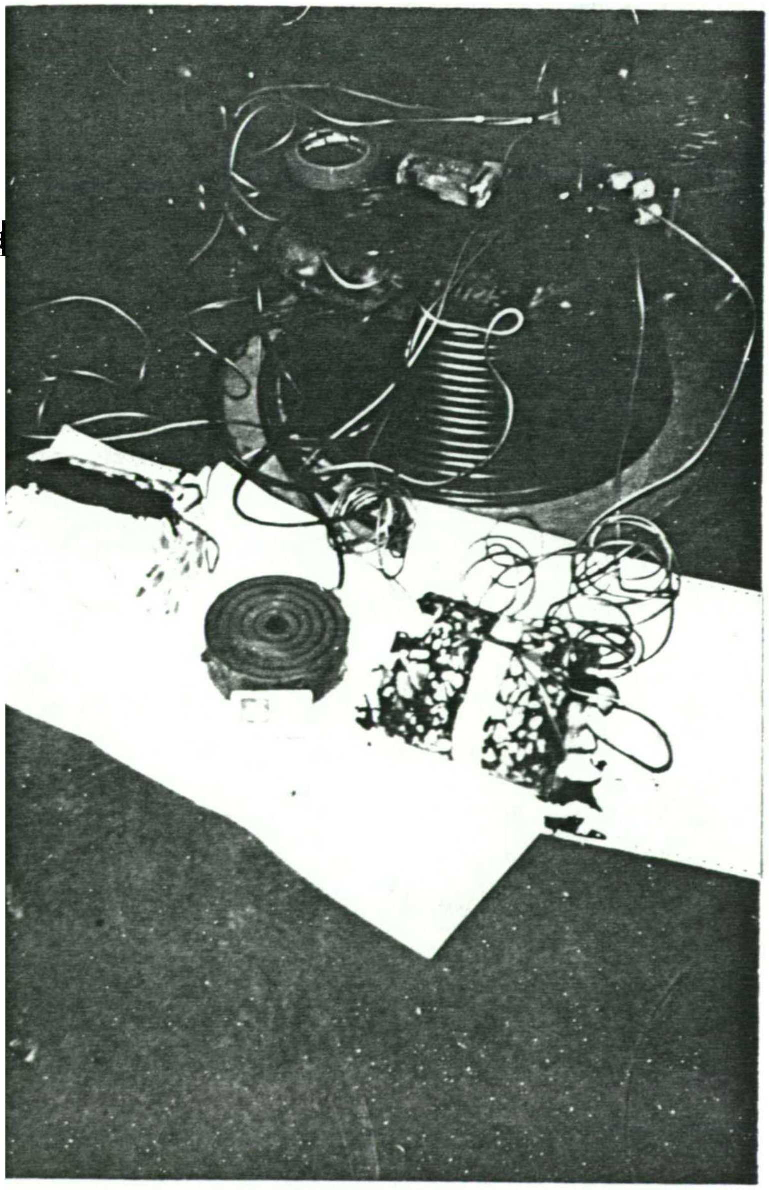
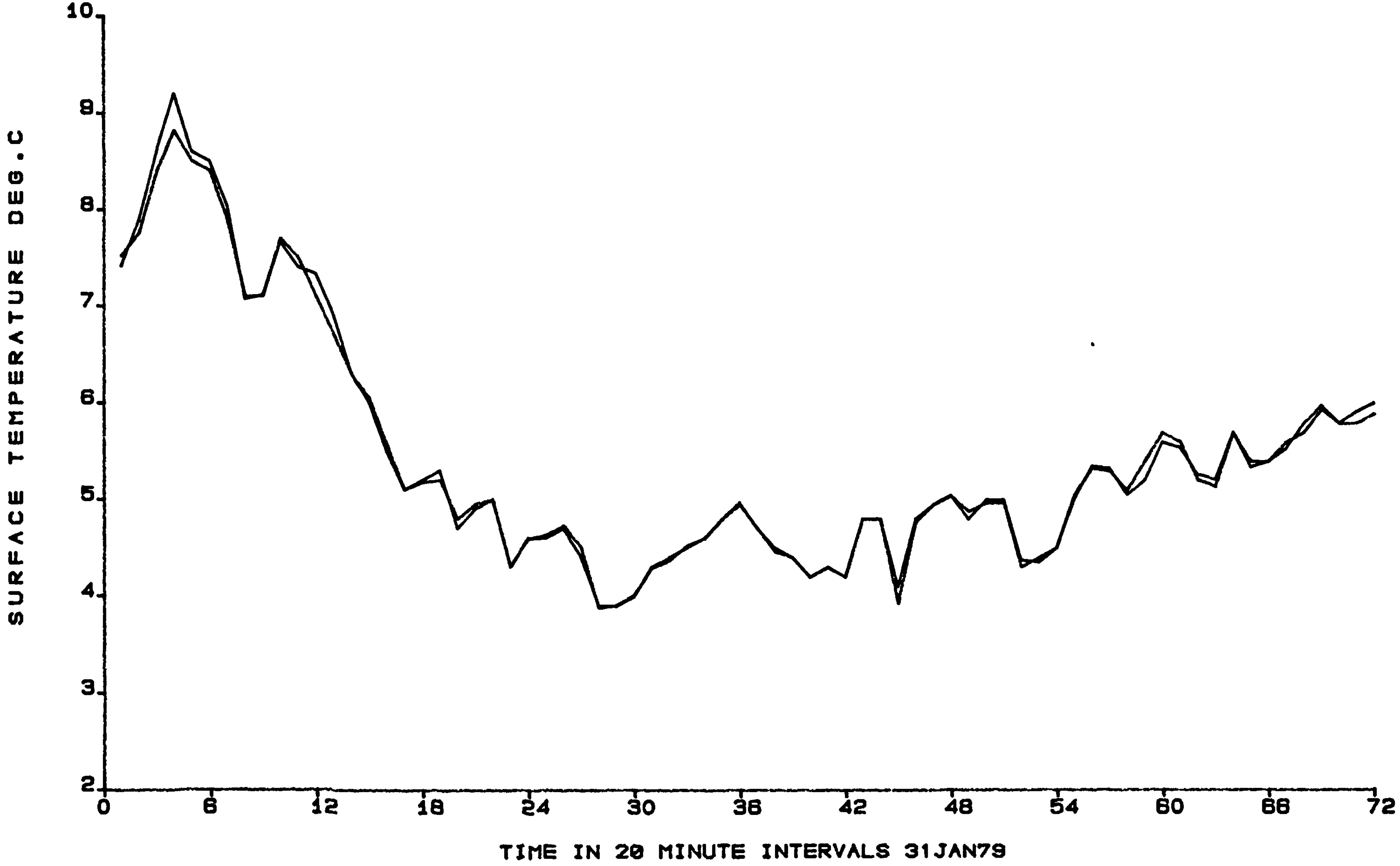


FIGURE 4.6 COMPARISON OF ROAD SURFACE TEMPERATURES FROM THE 2 SURFACE SENSORS



The instrument was interrogated every 10 minutes for an accumulated wind run which was then converted to metres per second. The wind direction vane did not function at all during the study period and for most of February and March 1980 the wind speed indicator also malfunctioned. Wind speeds from Beaufont Park and Benson (measured at 10 m) were adjusted to values applicable to the M4 site (see Chapter 6).

4.2.3 Surface Wetness

Instruments to measure surface wetness are notably unreliable in the field, despite rigorous laboratory tests. The device used here was developed by Hay and Young (1972) and consisted of five concentric brass rings connected electrically in alternate pairs. The largest ring has a diameter of 18 cm and a depth of 7 cm. An insulating filler mixture of epoxy resin and sand was used and the resistance between the alternate rings was measured by passing an electrical current through them. A wetness meter was installed in both the slab and the road for comparative purposes. However, it was found that the two instruments could only be compared in a qualitative way, and indeed the results from the instrument in the road proved to be uninformative. The resistance hardly changing at all which was probably due to the continuous excessive presence of rock salt due to over salting.

4.3 Data Collection

Data from the M4 site was first recorded on 30th January 1979. The data collection system was of course 'second hand' as were some of the instruments, and the microprocessor was very unreliable. It was built in 1972 and was subject to overheating and turning itself off whenever a slight power surge took place. During February 1979 the telephone line was flooded and all observations for the middle of February to the end of the winter period were lost. The data for the first half of the winter of 1979/80 was also lost due to a malfunction in the paper punch machine at the Transport and Road Research Laboratory. This system of data storage was replaced eventually with a cassette recorder. The data collection problems were wearing but much valuable experience in remote data collection was gained. In all more than a thousand hours of observations were recorded, and thirty nights when the minimum road surface temperature fell below 5°C have been selected for analysis. Table 4.3 lists these nights which will be discussed individually in Chapter 6.

4.4 Data Analysis

One of the most surprising results of the 30 nights data chosen for analysis is that the minimum road surface temperature was warmer than the minimum air temperature on 25 occasions. The Road Danger Warnings issued during that period for the M4 motorway always presumed that the motorway would be colder than the air. For instance, consider three Road Danger Warnings issued to the M4 maintenance depots:

(i) 23rd February 1980

'Minimum air temperature -2°C, minimum road -4°C. Road temperatures expected to fall below 0°C after 2000 hrs - no snow expected.'

(Actual minimum air temperature was -0.5°C, and the minimum road surface temperatue was 1.7°C)

Table 4.3 Air and Road Minimum Temperatures for 30 Nights on the M4 When the Minimum Road Surface Temperature was less then 5°C

	Date	Min. Air Temperature	Time	Min. Road Temperature	Time	ΔT_{R-A}
1	31-01F79	3.1	1800	3.9	2100	0.8 x M
2	01-02F79	1.4	0800	1.1	0800	-0.3 x H
3	02-03F79	-3.6	0440	-2.4	0440	1.2
4	03-04F79	-1.8	1120	-0.8	1120	1.0
5	04-05F79	2.0	0220	2.3	0240	0.3
6	05-06F79	-3.3	0620	-1.9	0420	1.4
7	06-07F79	0.9	1520	2.2	0200	1.3 x M
8	07-08F79	-0.1	0800	-0.6	0740	-0.5 x Tr
9	08-09F79	1.1	0500	1.5	0520	0.4
10	09-10F79	2.0	2000	2.2	0200	0.2
11	10-11F79	1.5	0820	1.4	2300	-0.1 x Tr
12	11-12F79	0.1	0540	0.6	0540	0.5 x M
13	12-13F79	1.0	1200	2.1	0200	1.1 x M
14	22-23F79	0.9	0500	2.9	0440	2.0 x H
15	23-24F80	-0.5	0240	1.7	0220	2.2
16	24-25F80	1.7	0400	2.7	0400	1.0 x L
17	25-26F80	-1.1	0020	2.0	0020	3.1 x L
18	03-04M80	-3.3	0520	-0.5	0520	2.8
19	04-05M80	-2.2	0440	0.4	0440	2.6
20	06-06M80	3.4	0304	3.6	0500	0.2 x H
21	07-08M80	3.0	0140	3.0	0100	0.0 x M
22	08-09M80	1.7	0300	3.0	0300	1.3
23	09-10M80	0.9	0120	4.2	0120	3.3 x M
24	10-11M80	2.6	0600	3.0	0300	0.4
25	20-21M80	-1.6	2400	-0.3	2400	1.3
26	21-22M80	-5.5	0620	-2.8	0540	2.7
27	22-23M80	1.2	2200	3.0	0400	1.8
28	01-02A80	3.9	0300	3.4	0400	-0.5 x H
29	02-03A80	3.0	0520	4.1	0500	1.1
30	03-04A80	-0.7	0440	2.3	0540	3.0
		[1]		[2]		[3]
		$\bar{x}_1 = 0.39$	$\sigma_1 = 2.34$	$\bar{x}_2 = 1.57$	$\sigma_2 = 1.92$	$\overline{\Delta T}_{R-A} = 1.2$

Signifi. diff. betw. [1] and [2] at 3.6% level [3]
n = 55 t = -2.15

correlation between [1] and [3] = -0.575
[2] and [3] = -0.119

Precipitation: H=Heavy, M=Medium, Tr=Trace

(ii) 24th February 1980

'Minimum air temperature +3°C, minimum road surface temperature 2°C'

(Actual minimum air temperature +1.7°C, mimimum road surface temperature +2.7°C)

(iii) 25th February 1980

'Minimum air temperature -2°C, minimum road surface temperature -3°C. Road temperature will fall below zero at 2100 hrs.'

(Actual minimum recorded air temperature -1.1°C, and minimum recorded road temperature +2.0°C).

Each forecast assumes that the minimum road temperature will be colder than the minimum air temperature, and in each case it was the other way around. Figure (4.7) shows the relationship between the minimum air and road temperatures for the 30 nights considered. Table 4.3 gives the actual figures used to plot Figure 4.7, and shows that on average the minimum motorway temperatures recorded at the M4 site were more than 1°C warmer than the minimum air temperatures. Table 4.4 shows that there is no significant*difference between the minimum air temperatures recorded at the M4 site and those recorded at R.A.F. Benson. Hence the air on the M4 is not unusually cold, it is the motorway that is unusually warm! The possible reasons for this will be discussed in detail later, but are primarily due to depth of road construction and traffic.

This result is very important in that it suggests that far too many Road Danger Warnings are being issued for this stretch of the M4. The evidence on which local weather centres base their belief that

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*The statistics carried out in this chapter were done using the statistical package MINITAB (Tyan et.al. 1976)

FIGURE 4.7

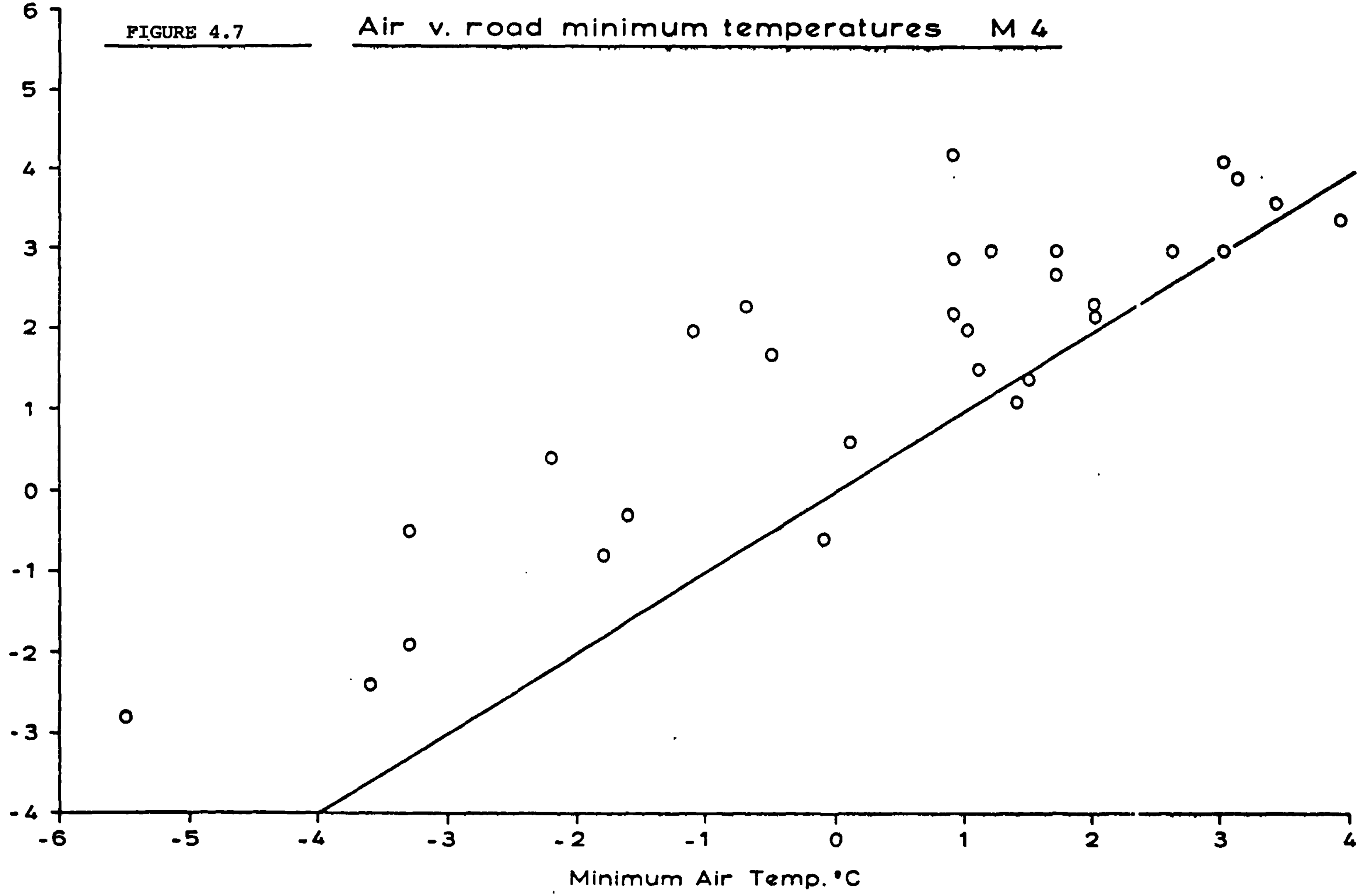

Air v. road minimum temperatures M 4
Minimum road Temperature °C
Minimum Air Temp. °C
6
5
4
3
2
1
0
-1
-2
-3
-4
-6
-5
-4
-3
-2
-1
0
1
2
3
4

Table 4.4 A Comparison of Minimum Air Temperatures at M4 Site and R.A.F. Benson for the 30 Nights Considered

	Date	M4	Benson	ΔT_{M4}-B
1	31-01F79	3.1	3.9	-0.8
2	01-02F79	1.4	0.2	+1.2
3	02-03F79	-3.6	-2.6	-1.0
4	03-04F79	-1.8	0.1	-1.9
5	04-05F79	2.0	0.5	+1.5
6	05-06F79	-3.3	-1.4	-1.9
7	06-07F79	0.9	0.1	+0.8
8	07-08F79	-0.1	-1.6	+1.5
9	08-09F79	1.1	1.7	-0.6
10	09-10F79	2.0	1.4	+0.6
11	10-11F79	1.5	1.2	+0.3
12	11-12F79	0.1	-0.5	+0.6
13	12-13F79	1.0	0.2	+0.8
14	22-23F79	0.9	-0.3	+1.2
15	23-24F79	-0.5	-1.3	+0.8
16	24-25F79	1.7	2.0	-0.3
17	25-26F79	-1.1	-2.9	+1.8
18	03-04M80	-3.3	-2.3	-1.0
19	04-05M80	-2.2	1.1	-3.3
20	06-07M80	3.4	3.3	+0.1
21	07-08M80	3.0	2.3	+0.7
22	08-09M80	1.7	1.3	+0.4
23	09-10M80	0.9	3.6	-2.7
24	10-11M80	2.6	1.1	+1.5
25	20-21M80	-1.6	-3.1	+1.5
26	21-22M80	-5.5	-2.5	-3.0
27	22-23M80	1.2	1.6	-0.4
28	01-02A80	3.9	3.3	+0.6
29	02-03A80	3.0	1.2	+1.8
30	03-04A80	-0.7	-1.0	+0.3

$\bar{x}_1 = 0.39$ $\bar{x}_2 = 0.35$ $\bar{x}_3 = 0.04$

Mean absolute difference = 1.16

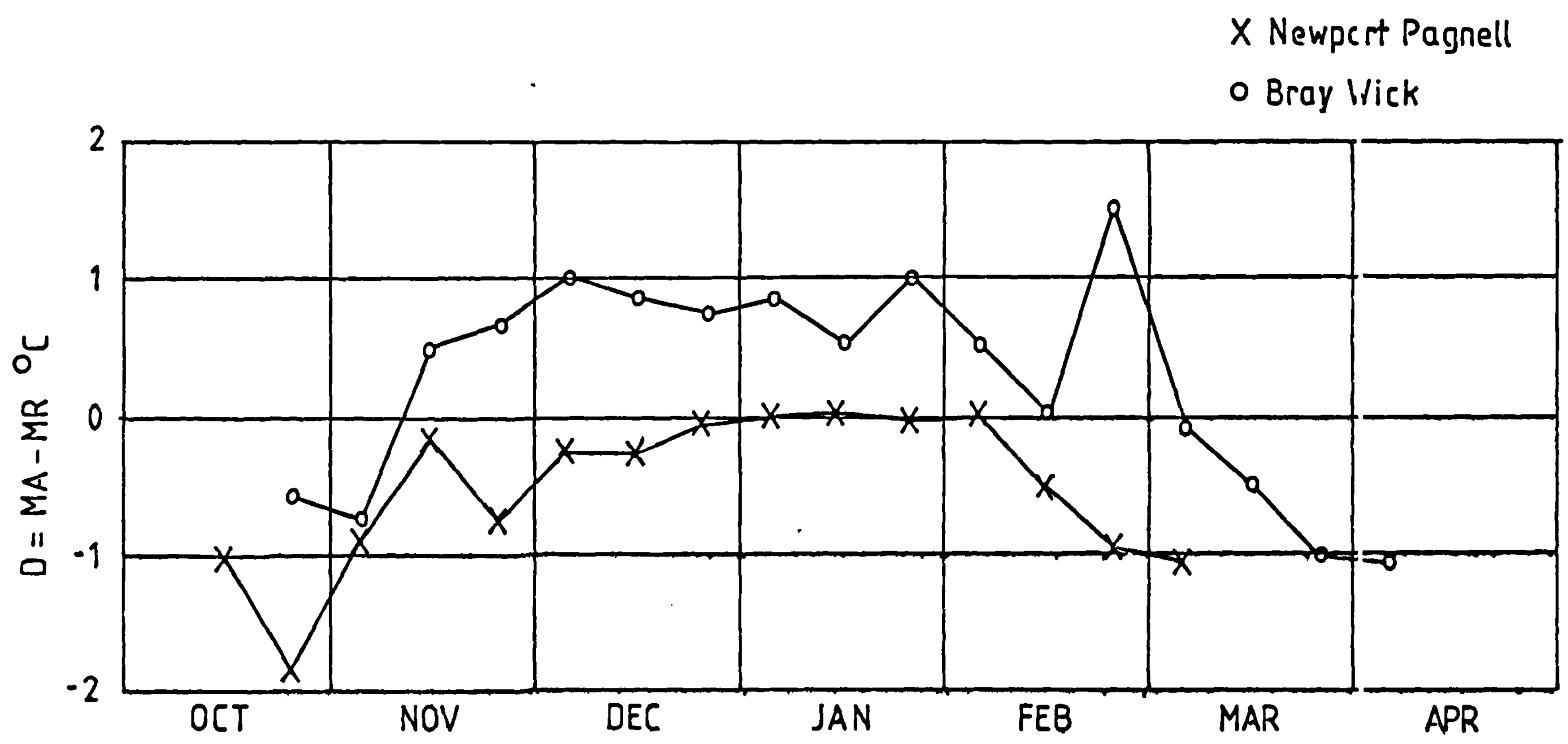
There is no significant difference between air minimum on M4 and at R.A.F. Benson (using a two sample t-test) minimum road temperatures tend to be colder than minimum air temperatures is based on a number of comparison studies done in the late 1960's and early 1970's. Ritchie (1969) showed that in winter the difference between the minimum road and air temperature: ΔT_{R-A} was on average about -1.5°C, i.e. that on average the road is colder. However the "road" in this case was a concrete road leading to an aircraft taxiway at Wyton. It was only six inches (15 cm) thick and had no traffic. A typical motorway construction involves 35-50 cm of asphalt and/or concrete on top of a similar depth of sub-base. Hence Ritchie's results are not typical for an ordinary road.

The only study that used actual motorway suface temperatures was that of Hay (1969). He used thermocouples embedded in the road at two sites - one on the M1 at Newport Pagnell and the other on a sliproad of the M4 near Bray Wick. The Newport Pagnell results are the most comparable in terms of road construction and traffic. Figure 4. 8 shows the 10-day means for the two winters of 1963/64 and 1964/65. These observations certainly show that the M1 minimum temperature was warmer that the minimum air temperature for most of the period, whereas on the sliproad of the M4 the converse is true. These figures have been largely ignored by Meterological Office forecasters who presumably are over swayed by grass minimum temperatures which are much colder than road temperatures. These differences will be examined again in Chapter 7 when a complete winters observations for the M5 and M42 are examined. Hay concludes from his study that there appeared to be no dependence of ΔT_{R-A} on:

(i) the road surface being wet or dry

(ii) traffic density (using hourly traffic counts at Newport Pagnell)

FIGURE 4.8 Variation of 10-day mean values of MA-MR (MAY 1969)



(iii) the value of air or road minimum temperature

(iv) the time interval, sometimes several hours, between the two minima

(v) the wet-bulb depression.

Let us compare each of these findings with the M4 data.

(i) Firstly the effect of the road being wet or dry.

Table 4.5 shows that on all 4 occasions when the ΔT_{R-A} was negative the road was wet at some time during the 24 hour period, and that, on average, the difference between road and air minimum temperatures is less on days when rain fell, and therefore the road was wet, although the difference is not significantly different with this sample size. This effect is no doubt due to the fact that the temperature of the precipitation is influenced by the air temperature, and hence tends to cancel out differences between the air and road temperature. The diurnal range of the road temperature is also reduced when the road is wet due to the high specific heat of water. The diurnal range of the air temperature is on average less than that of the road as shown in Table 4.6. The average diurnal range for the road temperatures is 9.2°C, and for the air temperatures is 6.8°C (the difference is significant at the 2% level).

Figure 4.9 shows the average diurnal curves for all the February and March data in 1979 and 1980 (27 nights). This clearly shows that the road minimum is on average greater than the air minimum.

Table 4.6 suggests that the diurnal range for both the air and the road temperature is suppressed when precipitation is present. Also it

Table 4.5 ΔT_R-A for Dry and Wet Road Conditions

Road Dry ΔT_R-A	Road Wet at Sometime in 24 Hours ΔT_R-A
1.2	0.8
1.0	-0.3
0.3	1.3
1.4	-0.5
0.4	-0.1
0.2	0.5
2.2	1.1
2.8	2.0
2.6	1.0
1.3	3.1
0.4	0.2
1.3	0.0
2.7	3.3
1.8	-0.5
1.1	
3.0	
$\Sigma = 23.7$	$\Sigma = 11.9$
$\overline{\Delta T_R\text{-A}} = \underline{\underline{1.5°C}}$	$\overline{\Delta T_R\text{-A}} = \underline{\underline{0.85°C}}$
$\sigma = 0.94$	$\sigma = 1.34$

No significant difference between them at 5% (Sig. at 13%)

$n = 24$

$t = 1.56$

AVERAGE DIURNAL ROAD AND AIR TEMPERATURE FOR THE M4 FEBRUARY/MARCH 1979/80

FIGURE 4.9

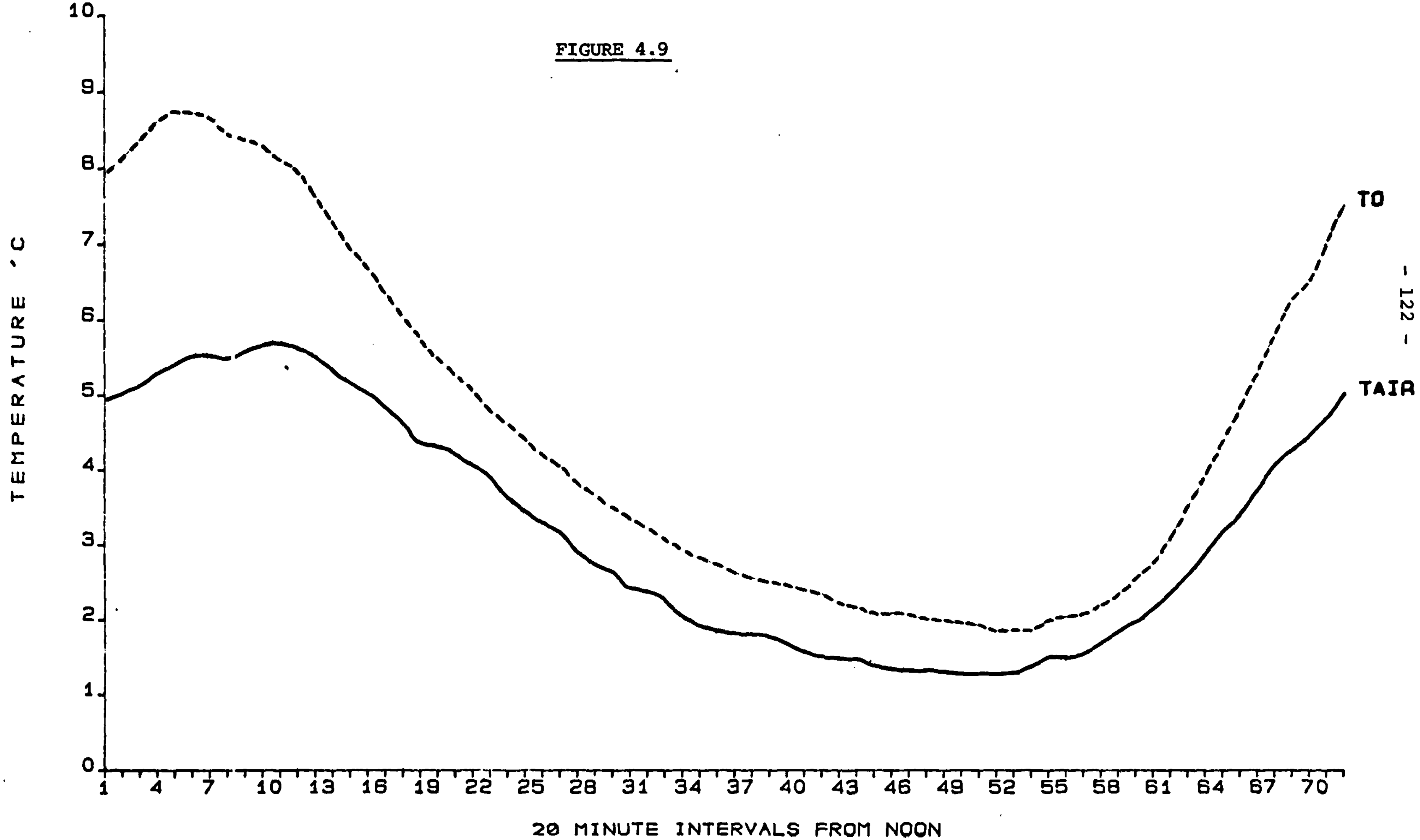


Table 4.6

Observed Diurnal Ranges of Air, Road and Slab Temperatures on M4

	Date	Slab	Road	Air	ΔT_{R-A}	Moisture
1	31-01F79	6.5	5.1	3.8	1.3	✓
2	01-02F79	8.0	7.1	7.8	-0.7	✓
3	02-03F79	10.5	10.4	7.9	2.5	
4	03-04F79	10.5	9.4	7.9	1.5	
5	04-05F79	6.2	4.6	2.8	1.8	
6	05-06F79	10.9	9.5	8.9	0.6	
7	06-07F79	4.9	4.7	4.5	0.2	✓
8	07-08F79	9.8	7.4	6.4	1.0	✓
9	08-09F79	4.0	4.2	2.5	1.7	
10	09-10F79	3.7	3.8	1.8	2.0	
11	10-11F79	3.8	4.5	1.7	2.8	✓
12	11-12F79	2.8	3.0	2.7	0.3	✓
13	12-13F79	5.2	3.3	5.6	-2.3	✓
14	22-23F80	9.8	7.4	8.4	-1.0	✓
15	23-24F80	11.2	8.6	8.8	-0.2	
16	24-25F80	7.1	5.4	4.8	0.6	✓
17	25-26F80	13.2	10.3	9.1	1.2	✓
18	03-04M80	18.6	14.9	10.7	4.2	
19	04-05M80	17.3	15.2	11.5	3.7	
20	06-07M80	7.1	6.4	7.3	-0.7	✓
21	07-08M80	7.5	6.1	4.6	1.5	✓
22	08-09M80	12.3	11.5	6.9	4.6	
23	09-10M80	13.3	12.1	8.5	4.6	✓
24	10-11M80	11.9	10.4	6.5	3.9	
25	20-21M80	14.7	13.8	5.9	7.9	
26	21-22M80	18.1	15.3	11.0	4.3	
27	22-23M80	15.9	12.9	6.9	6.0	
28	01-02A80	14.7	13.4	6.5	6.9	✓
29	02-03A80	20.0	15.5	9.1	5.4	
30	03-04A80	24.9	19.6	12.1	7.5	
		$\bar{x}_1 = 10.8$	$\bar{x}_2 = 9.2$	$\bar{x}_3 = 6.8$	$\bar{x}_4 = 2.4$	
		$\sigma_1 = 5.5$	$\sigma_2 = 4.5$	$\sigma_3 = 2.9$	$\sigma_4 = 2.6$	

[1] No significant difference between slab and road diurnal temperatures (21% level) $n = 55$ $t = 1.26$

[2] Significant difference between road and air diurnal temperatures at 2% level $n = 49$ $t = 2.5$

can be seen that the difference between the diurnal ranges is smaller with precipitation. Interestingly, Table 4.7 also shows that there is a significant difference between the diurnal range of the road temperature on wet and dry days; whereas the difference on the same days for the diurnal air temperature is not significant. The differences between the diurnal road and air temperatures ΔT_{R-A} is significantly greater on dry days, again showing that precipitation "dampens" the diurnal road surface temperature range. Thus precipitation does have an effect upon the difference between the air and road temperatures for the M4.

(ii) The effect of traffic density on road and air temperatures is little understood. Traffic counts for the M4 are not available in sufficient detail to test any hypothesis, but from more recent data gathered in the West Midlands it certainly does appear that traffic intensity affects road temperatures. Hay (1979) only measured temperatures in one lane - the slow lane, and similarly the instruments for this investigation were placed in the slow lane of the M4. Hence, it is difficult to sample out the effect of traffic, as the diurnal rhythm of temperature is confused with the diurnal rhythm of traffic. In the West Midlands we have instrumented both the slow and fast lanes of three sites. This immediately gives us a comparison, as traffic is more frequent in the slow lanes. We have found that the fast lane of a busy motorway can be up to 2°C colder than the slow lane which must be due to less traffic as all else is constant. Traffic density must therefore affect the difference between the air temperature minimum and the road temperature minimum, depending upon which lane the road temperature is taken. This is discussed further in Chapter 7.

Table 4.7

Diurnal Ranges of Air and Road Temperatures on Dry and Wet Days

Road		Air		ΔT_{R}-A	
Dry	Wet	Dry	Wet	Dry	Wet
10.4	5.1	7.9	3.8	2.5	1.3
9.4	7.1	7.9	7.8	1.5	-0.7
4.6	4.7	2.8	4.5	1.8	0.2
9.5	7.4	8.9	6.4	0.6	1.0
4.2	4.5	2.5	1.7	1.7	2.8
3.8	3.0	1.8	2.7	2.0	0.3
8.6	3.3	8.8	5.6	-0.2	-2.3
14.9	7.4	10.7	8.4	4.2	-1.0
15.2	5.4	11.5	4.8	3.7	0.6
11.5	10.3	6.9	9.1	4.6	1.2
10.4	6.4	6.5	7.3	3.9	-0.7
13.8	6.1	5.9	4.6	7.9	1.5
15.3	12.1	11.0	8.5	4.3	3.6
12,9	13.4	6.9	6.5	6.0	6.9
15.5	av = 6.9	9.1	av = 5.8	6.0	av = 1.05
19.6	σ = 3.1	12.1	σ = 2.3	7.5	σ = 2.3
av = 11.2		av = 7.6		av = 3.6	
σ = 4.5		σ = 3.2		σ = 2.4	
Significant difference at < 1%		No Significant difference at < 9%		Significant difference at < 1%	
n = 26 t = 3.1		n = 27 t = 1.747		n = 27 t = 3.001	

(iii) The size of the difference ΔT_{R-A} can be correlated against the actual values of T_{RMin} and T_{AMin} from Table 4.3 to test this hypothesis. Interestingly, there is a significant correlation ($r = -0.58$) between the minimum air temperature and ΔT_{R-A}, whereas the relationship between the minimum road temperature and ΔDT_{R-A} is not significant ($r = -0.12$). Thus the colder the minimum air temperature the greater the difference ΔT_{R-A}. This is probably because the road temperature does not drop as cold as one might expect due to traffic or perhaps the spreading of salt which tends to create a moist layer on the surface of the road as salt is hydroscopic. This moist layer then insulates the surface from further cooling.

(iv) and (v) The times of the minima for air and road are remarkably similar and no pattern can be seen relating the difference ΔT_{R-A} to either the time of the minima or the difference in timings of the minima. Table 4.3 shows that the absolute minima occured at times ranging from well before midnight through to times around dawn. The average minima for 27 nights (excluding April figures in 1980) can be seen in Figure 4. 9 . The air temperature curve is more sinusoidal than the road temperature curve which has a much larger interval between maximum and minimum (15 hours).

(vi) the effect of the air humidity will be discussed when the sensitivity of the prediction model is examined later. Wet bulb temperatures were not measured at the site.

Thus, of Hay's conclusions, (1), (2) and (3) are not supported by the M4 data whereas (4) and (5) are. A factor ignored by Hay was the effect of wind speed in the difference between the road and air minimums.

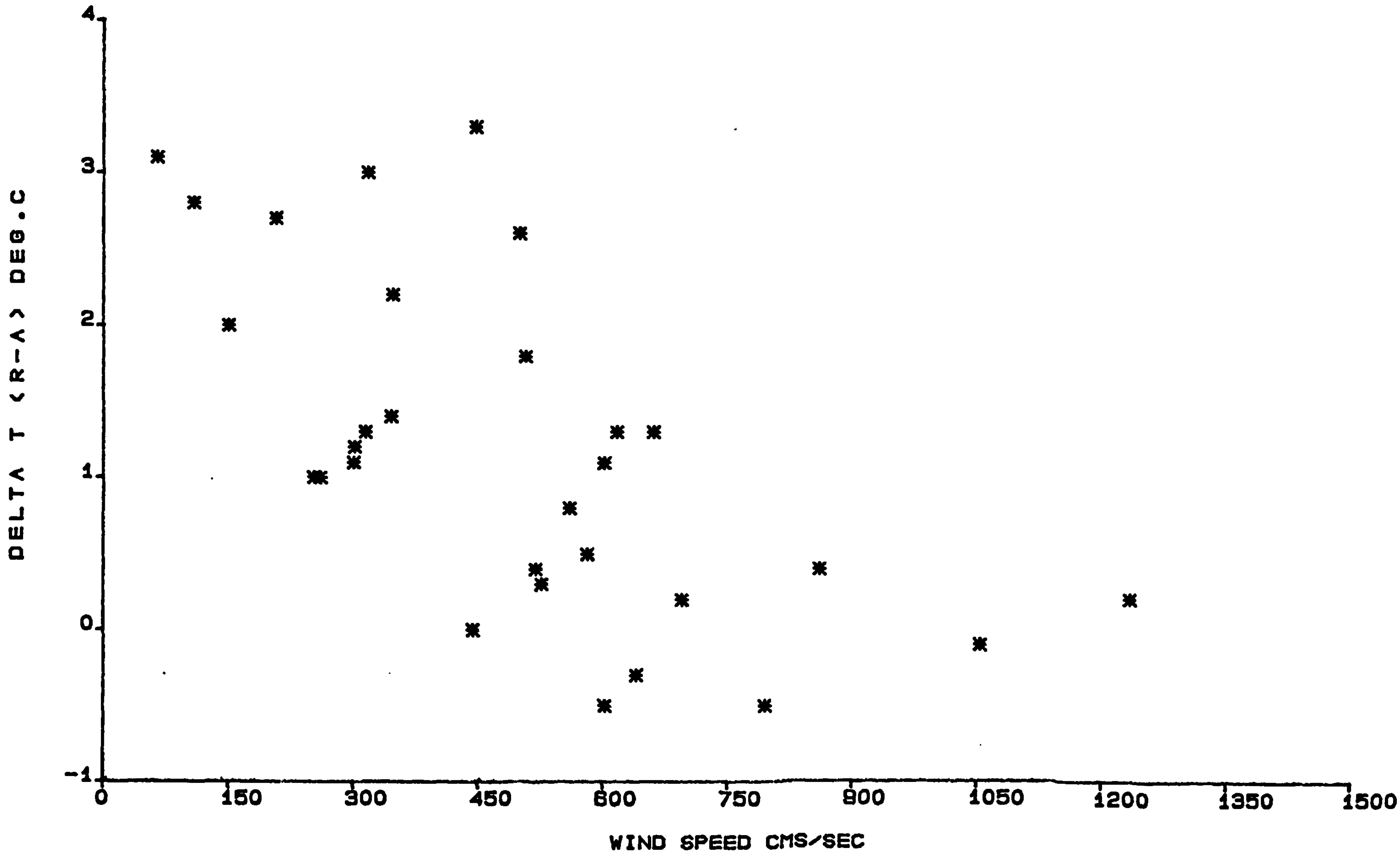
Figure 4.10 shows that there is an inverse relationship between the two, with a correlation coefficient of -0.64. This is instinctively obivious, the higher the windspeed the greater the mixing and hence the less the difference between the air and road surface minimum temperature.

Hay (1969) applied his results to the problem of forecasting minimum road temperatures and states (p59):

'it would appear that forecast values of minimum road surface temperature should be taken to be the same as forecast values of minimum air temperatures for the period mid-November to mid-February. This however, should perhaps be regarded at the present stage as a guide rather than a rule in view of the limited amount of data, two incomplete winters at each site. It may be, too, that a different result would be obtained at another site with different topographical features and physical characteristics such as type of road construction, colour of surface etc.'

Hay recognised the possible limitations of his results, indeed he was the co-instigator of the instrumentation of the M4 (Hay and Young 1972). With only 30 nights of more detailed observations the same criteria must be applied to the data presented in this study. Results from the West Midlands discussed in Chapter 7 show that ΔT_{R-A} is different for each motorway considered. The site of the M4 instrumentation could well be an important factor influencing the observed warmth of the motorway surface compared to the air temperature. Another factor could be the different instrumentation itself. The problems of measuring the 'true' road surface temperature are great and most measure just below the surface, but perhaps the greatest factor that has not been considered in previous literature is the traffic density.

FIGURE 4.10 TEMPERATURE DIFFERENCE ROAD AND AIR VERSUS WIND SPEED



The above comparison of results with Hay's investigation does not complete the analysis of the range of data collected on the M4 site. Other data included the slab and sub-road temperatures.

4.5 Slab Temperatures

Table 4.6 compares the diurnal range of the slab surface temperatures with that of the road and the air. The average range for the slab is 10.8°C as compared to 9.2°C for the road. Table 4.8 compares the maximum and minimum temperatures for the slab and the M4. On all 30 nights the slab minimum is lower than the road minimum. This is the result of two main factors, firstly the exposure of the slab which was standing above the surface, and secondly the presence of traffic on the road. The first factor kept the slab colder than the road and the traffic kept the road warmer. Unfortunately it is difficult to isolate these two effects which act together to give colder slab minimum temperatures. As far as the maximums are concerned it seems that there is a difference between the 1979 figures and the 1980 figures. On average in 1979 (13 nights) the maximum slab temperature was colder than the maximum road temperature by -0.8°C, whereas in 1980 (17 nights) the average slab maximum temperature was warmer by +1.2°C. There are probably two reasons for this. February 1979 followed the very cold month of January 1979 which could have cooled the slab below that of the road because of it's exposure.

The data also shows that the slab temperature at 36 cm below the surface was about 2°C lower than that of the road temperature at 36 cm for the nights studied in 1979. The 1980 nights showed a difference of less than 1°C. The data for 1980 is for early spring when the sun was beginning to raise the daytime maximums above 10°C. Figures 4.11 and 4.12 show the slab being installed, and it's position relative to the road and the 'xmas tree'. The

Table 4.8

Maximum and Minimum Temperatures of Slab and M4

		Maximums				Minimums			
		Slab	M4	ΔS-M4		Slab	M4	ΔS-M4	
1	31-01F79	8.7	9.0	-0.3		2.2	3.9	-1.7	
2	01-02F79	7.8	8.2	-0.4		-0.2	1.1	-1.3	
3	02-03F79	6.4	8.0	-1.6		-4.1	-2.4	-1.7	
4	03-04F79	7.9	8.6	-0.7		-2.6	-0.8	-1.8	
5	04-05F79	7.0	6.9	+0.1		0.8	2.3	-1.5	
6	05-06F79	6.4	7.6	-1.2		-4.5	-4.5	-2.6	
7	06-07F79	5.9	6.9	-1.0		1.0	2.2	-1.2	
8	07-08F79	6.3	6.8	-0.5		-2.5	-0.6	-1.9	
9	08-09F79	4.5	5.7	-1.2		0.5	1.5	-1.0	
10	09-10F79	5.0	6.0	-1.0		1.3	2.2	-0.9	
11	10-11F79	4.6	5.9	-1.3		0.8	1.4	-0.6	
12	11-12F79	2.7	3.6	-0.9		-0.1	0.6	-0.7	
13	12-13F79	6.2	6.7	-0.5	$\overline{\Sigma 79}$ = -0.8	1.0	2.1	-1.1	$\overline{\Sigma 79}$ = -1.4
14	22-23F80	11.3	10.3	1.0		1.5	2.9	-1.4	
15	23-24F80	11.2	10.3	0.9		0.0	1.7	-1.7	
16	24-25F80	8.7	8.1	0.6		1.6	2.7	-1.1	
17	25-26F80	14.0	12.3	1.7		0.8	2.0	-1.2	
18	03-04M80	17.1	14.4	2.7		-1.5	-0.5	-1.0	
19	04-05M80	16.8	15.6	1.2		-0.5	0.4	-0.9	
20	06-07M80	10.0	10.0	0.0		2.9	3.6	-0.7	
21	07-08M80	9.3	9.1	0.2		1.8	3.0	-1.2	
22	08-09M80	14.1	15.5	-0.4		1.8	3.0	-1.2	
23	09-10M80	16.6	16.3	0.3		3.3	4.2	-0.9	
24	10-11M80	13.6	13.4	0.2		1.7	3.0	-1.3	
25	20-21M80	13.0	13.5	-0.5		-1.7	-0.3	-1.4	
26	21-22M80	13.5	12.5	1.0		-4.6	-2.8	-1.8	
27	22-23M80	18.3	15.9	2.4		2.4	3.0	-0.6	
28	01-02A80	17.4	16.8	0.6		2.7	3.4	-0.7	
29	02-03A80	20.0	15.5	4.5		2.5	4.1	-1.6	
30	03-04A80	26.6	21.9	4.7		1.7	2.3	-0.6	
		$\bar{x}_1$ = 11.03	$\bar{x}_2$ = 10.7	$\bar{x}_{3_{80}}$ = 1.2		$\bar{x}_4$ = 0.33	$\bar{x}_5$ = 1.57	$\bar{x}_{6_{80}}$ = -1.1	

No signf. diff. $\bar{x}_1$ and $\bar{x}_2$ n = 54 t = 0.27 (78%)

$\bar{x}_4$ and $\bar{x}_5$ are signf. diff. n = 57 t = -2.33 (2% level)

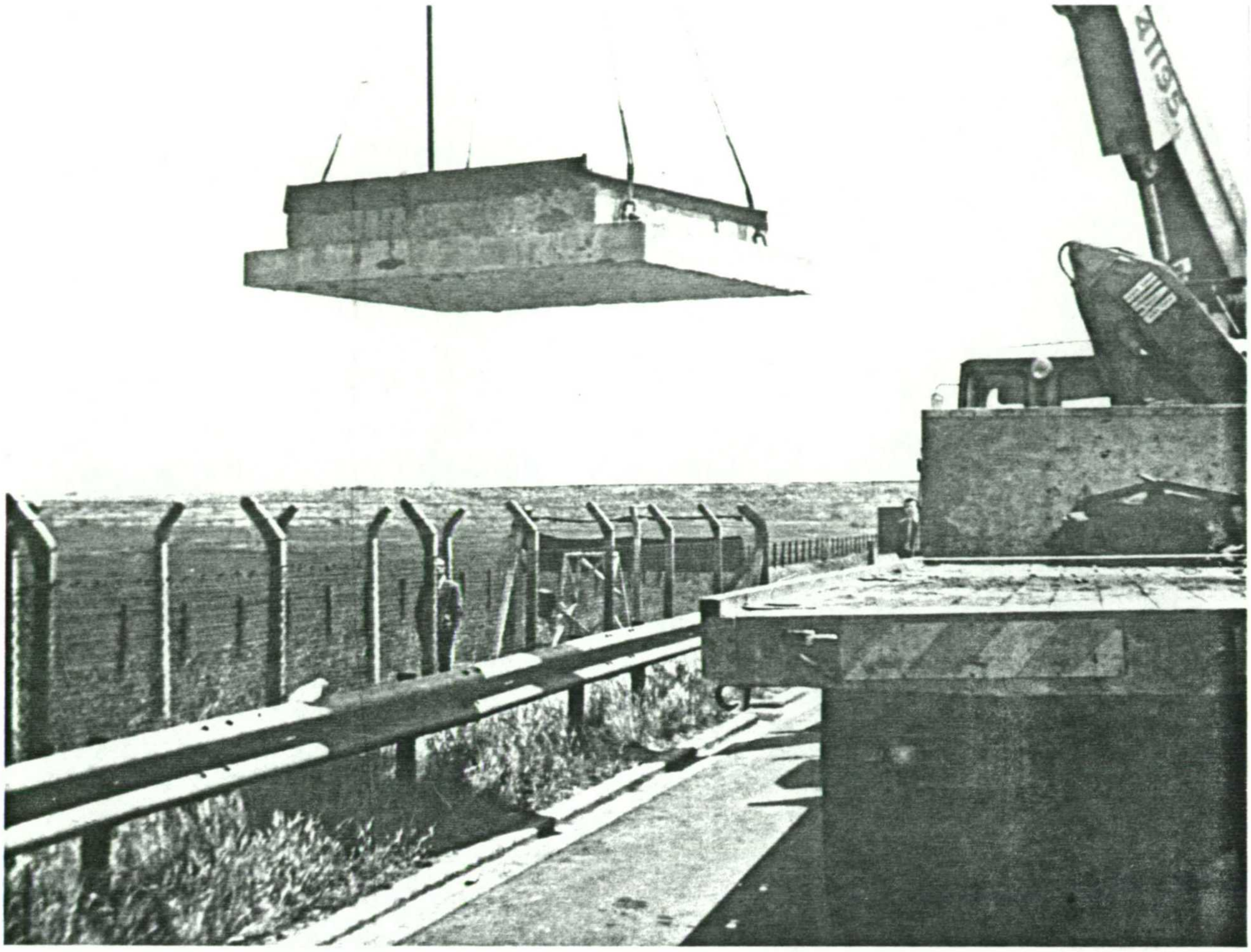


FIGURE 4.11 The slab being installed in the M4 compound

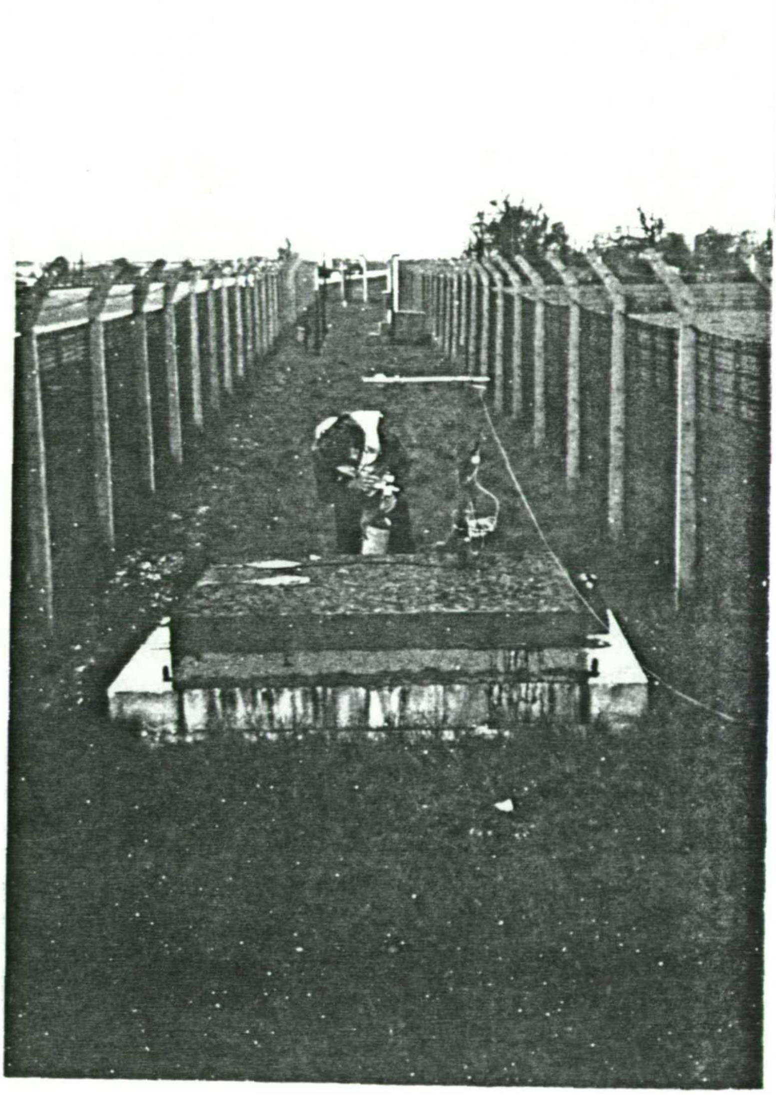


FIGURE 4.12 The instrumented slab in position

traffic on the road prevents the solar radiation reaching the surface, and when the sun is sufficiently high this can outweigh the heating effect of the traffic.

Thus the effect of trafficcannot be fully isolated from the analysis of slab temperatures due to the exposure of the slab. However it does suggest that the traffic is having no more of a heating effect than about 1°C in the slow lane. The fast lane and middle lane might well be affected by less than 0.5°C depending on the timing of dawn, and the timing of the build up of early morning traffic. Dawn on the 1st of February 1979 was about 7.40 am, whereas on the 1st April 1980 it was about 5.40 am.

Figure 4.13plots the variations in resistance measured by the road and slab "wetness" meters. Sugrue (1980) compared the measured resistances with actual rainfall measurements at nearby weather stations. He found that the resistance in the road hardly moved at all during the study period, and that the slab resistance was qualitatively better. These instruments are hardly reliable however, and are not being used in more recent studies.

4.6 Sub Road Temperatures

Temperatures measured at noon at 18 cm and 36 cm below the road for each of the 30 days considered are given in Table 4.9. (The actual diurnal temperatures are given in Figures (6.2 - 6.31) together with forecast values). Interestingly, there is no significant difference between the temperatures recorded at these depths. The greatest differencesoccur when the surface temperature gets above 10°C in 1980 and then the 18 cm temperature tends to be warmer than the 36 cm tempera-

FIGURE 4.13

An example of road and slab wetness

February 7th 1979

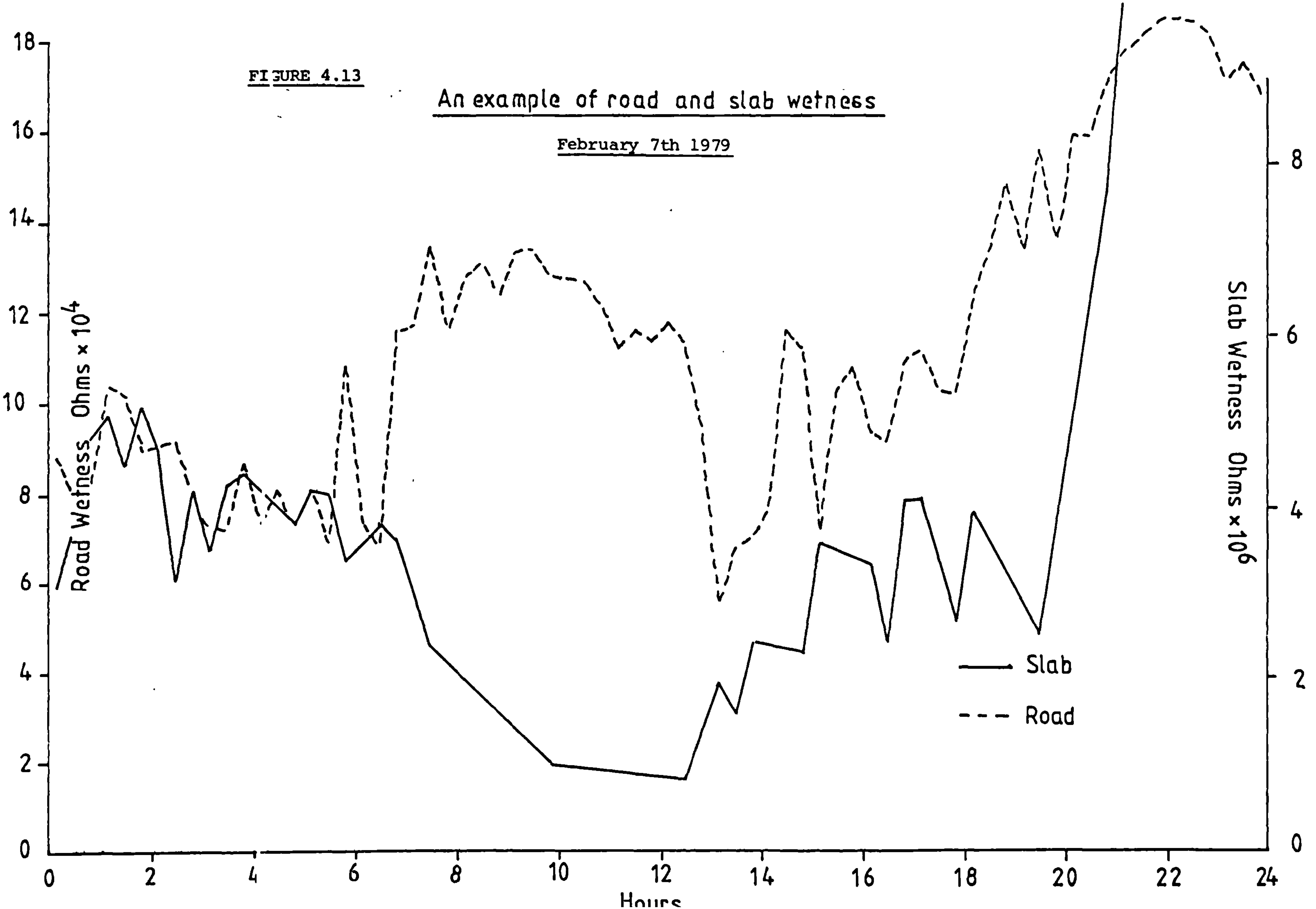


Table 4.9

Temperature at Noon at 18 and 36 cm Depth on the M4

	Date	$T_{surface}$	T18	T36	ΔT_{18-36}
1	31-01F79	7.5	2.8	2.2	0.6
2	01-02F79	6.3	4.9	4.0	0.9
3	02-03F79	8.0	4.2	4.1	0.1
4	03-04F79	6.8	2.3	2.6	-0.3
5	04-05F79	4.3	2.6	2.6	0.0
6	05-06F79	7.0	4.4	3.5	0.9
7	06-07F79	5.9	2.2	2.6	-0.4
8	07-08F79	6.1	4.0	3.4	0.6
9	08-09F79	4.6	2.7	2.7	0.0
10	09-10F79	5.5	3.2	3.0	0.2
11	10-11F79	5.7	3.7	3.4	0.3
12	11-12F79	3.3	2.7	3.1	-0.4
13	12-23F79	2.8	2.4	2.9	-0.5
14	13-14F80	8.5	8.8	8.4	0.4
15	14-15F80	7.4	5.8	6.9	-1.1
16	15-16F80	6.5	5.3	6.2	-0.9
17	16-17F80	10.2	6.0	6.1	-0.1
18	03-04M80	13.3	7.8	7.4	0.4
19	04-05M80	13.1	6.2	6.0	0.2
20	05-06M80	7.7	6.8	6.6	0.2
21	06-07M80	8.2	7.0	6.7	0.3
22	08-09M80	7.6	6.5	6.4	0.1
23	09-10M80	14.1	7.8	6.3	1.5
24	10-11M80	13.4	7.8	7.0	0.8
25	20-21M80	9.2	5.2	4.6	0.6
26	21-22M80	9.5	4.8	4.7	0.1
27	22-23M80	13.1	5.0	3.8	1.2
28	01-02A80	12.8	12.3	9.5	2.8
29	02-03A80	17.4	10.0	8.1	1.9
30	03-04A80	19.5	10.8	8.7	2.1
		$\bar{x}_1 = 8.84$	$\bar{x}_2 = 5.12$	$\bar{x}_3 = 5.12$	$\bar{x}_4 = 0.4$
		(1)	(2)	(3)	(4)

(2) and (3) not signf. diff. n = 55 t = 0.67 (51%)

	(1)	(2)	(3)
(2)	0.81		
(3)	0.71	0.96	
(4)	0.71	0.7	0.46

ture. In view of the fact that all the 30 days of observations were in the early part of the year the temperatures at these depths are at their lowest of the year. In autumn and early winter the temperatures at depth are much warmer and this can offset surface cooling, but as will be shown later, not to any great extent. Figure 4.14 shows the diurnal temperature curves for the surface, 18 cm and 36 cm for the first 5 days of continuous observations in February 1979.

4.7 Maintenance Depot Action

The maintenance depot responsible for the salting of the M4 where the instruments are installed is at Chieveley. The depot is required to keep a diary of action taken and weather forecasts received. Unfortunately the records are seldom complete, especially on nights when salting took place. The duty engineer is too busy organising the salting operation to fill in the diary. Hence a more complete record is usually found on nights when no action was taken, as the duty engineer has plenty of time to fill in the diary! Table 4.10 gives the forecast and observed minimum surface temperatures as recorded at the depot which has a thermistor buried just at the surface of the maintenance compound as shown in Figure 4.15. Table 4.10 also shows the observed minimum temperature on the M4 for comparison with the observed minimum temperatures at the depot. The minimum on the M4 is on average for 15 nights 1.3°C warmer than the minimum recorded in the compound. This reinforces the approximate 1°C warming considered to be due to traffic.

The Road Danger Warnings received from Upavon Meteorological Office contain forecast road minimum temperatures as shown in Table 4.10.

FIGURE 4.14 COMPARISON OF 10 MINUTE TEMPERATURES AT TO AND AT 18CM AND 36CM

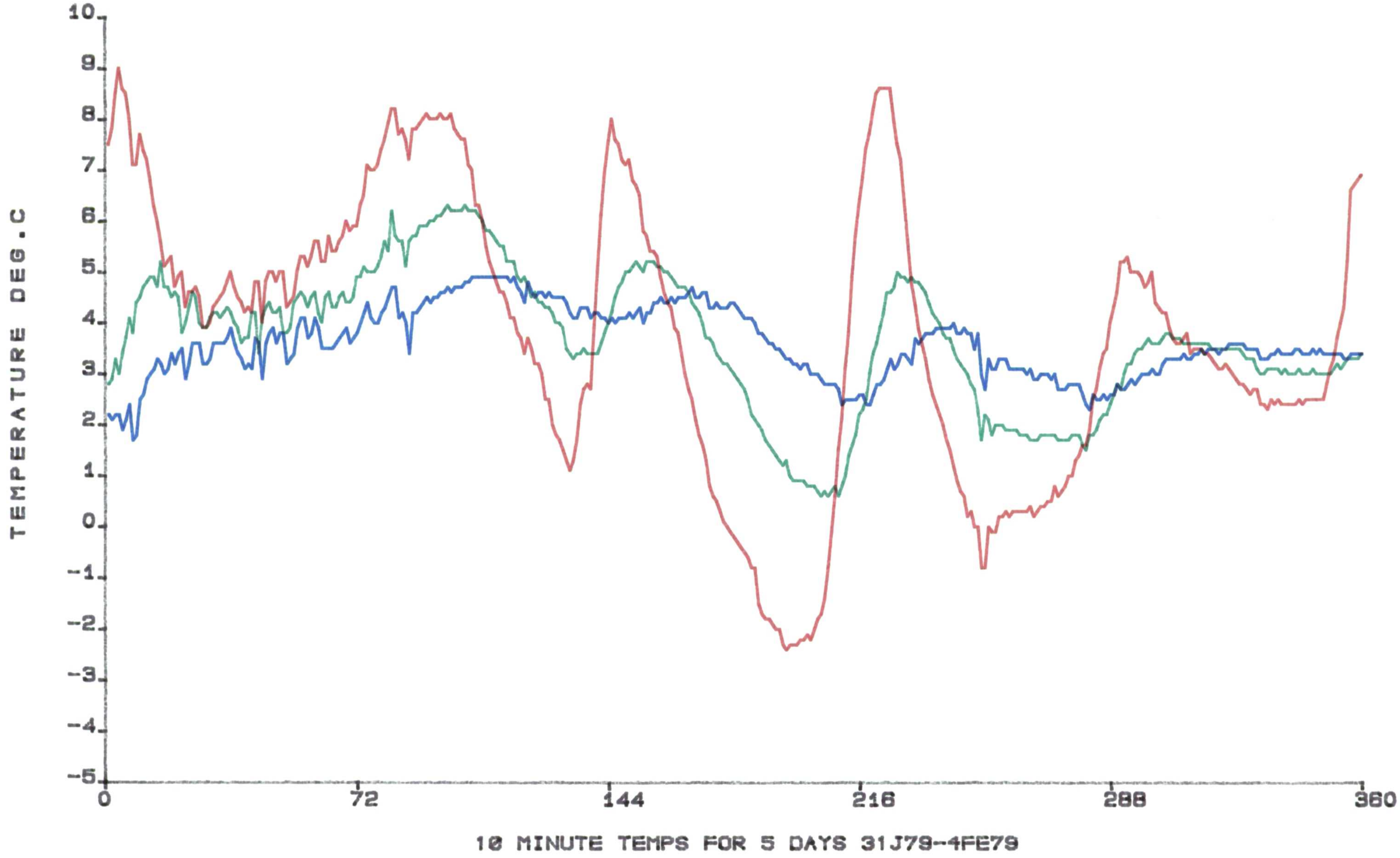


Table 4.10

Road Danger Warnings Received by M4 Motorway Maintenance Depot for 30 Nights Considered

	Date	Forecast Min. R.S.T.	Observed M4 Min	$\Delta TF-A$	Observed Compound Min. (1980 only)	ΔT_{M4}-Compound
1	31-01F79	-5.0	3.9	-8.9		
2	01-02F79	0.0	1.1	-1.1		
3	02-03F79	-7.0	-2.4	-4.9		
4	03-04F79	<0.0	-0.8			
5	04-05F79	0.0	2.3	-2.3		
6	05-06F79	-7.0	-1.9	-5.1		
7	06-07F79	-3.0	2.2	-5.2		
8	07-08F79	-5.0	-0.6	-4.4		
9	08-09F79	-4.0	1.5	-5.5		
10	09-10F79	<0.0	2.2			
11	10-11F79	0.0	1.4	-1.4		
12	11-12F79	<0.0	0.6			
13	12-13F79	0.0	2.1	-2.1		
14	22-23F80	1.0	2.9	-1.9	0.5	2.4
15	23-24F80	-4.0	1.7	-5.7	-0.9	2.6
16	24-25F80	2.0	2.7	-0.7	1.0	1.7
17	25-26F80	-3.0	2.0	-5.0	0.9	1.1
18	03-04M80	-7.0(-5.0)	-5.0	-4.5	-1.8	1.3
19	04-05M80	<0.0	0.4		0.4	0.0
20	06-07M80	2.0	3.6	-1.6	3.0	0.6
21	07-08M80	2.0	2.0	-1.0	1.2	1.8
22	08-09M80	-1.0	3.0	-4.0	3.8	-0.8
23	09-10M80	n.a.	4.2		2.0	2.2
24	10-11M80	-1.0	3.0	-4.0	0.9	2.1
25	20-21M80	-2.0(-6.0)	-0.3	-5.7	-2.1	1.8
26	21-22M80	-3.0(-5.0)	-2.8	-2.2	-3.9	1.1
27	22-23M80	n.a.	3.0		2.8	0.2
28	01-02A80	2.0	3.4	-1.4	1.8	1.6
29	02-03A80	0.0	4.1	-4.1	n.a.	
30	03-04A80	-2.0	2.3	-4.3	n.a.	$\bar{x}$ = 1.3°C
			$\overline{\Delta TF-A}$	$\doteq$ -3.4°C		

Figures in brackets represent updated forecasts

n.a. data not recorded

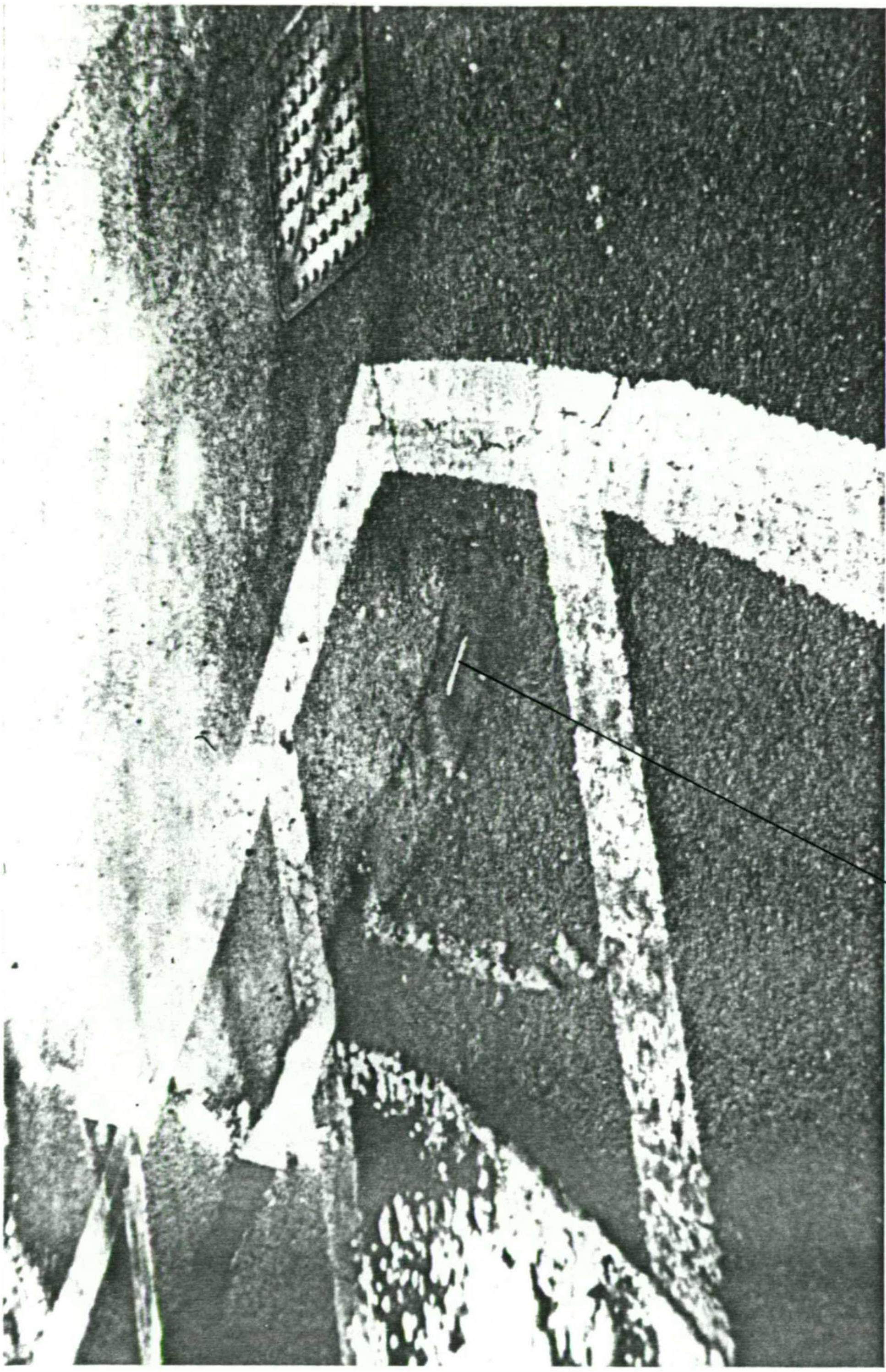


FIGURE 4.15 Thermocouple in yard of Chieveley Maintenance Depot

The inaccuracy of the Road Danger Warnings is clear. Even assuming that the fast lane might be 1°C cooler at night than the slow lane, the minimum road surface temperature forecast is too low. For the 24 nights when definite forecast minimum temperatures were made, the forecast minimum was on average 3.6°C too low.

It is hoped to present in the next two chapters an objective forecasting method which will be accurate retrospectively to within 1°C of observed motorway minimum temperatures, and accurate in real time to within 1.5°C, as presented in Chapter 7.

CHAPTER 5 THE FORTRAN MODEL

5.1 Introduction

Outcalt's (1971) model was chosen because it is easily modified to produce a 24 hour forecast of road surface temperatures. It has many assumptions that have to be borne in mind when interpreting the outputs, but it has the overwhelming advantage that is is easy to use and doesnot take up much computer time. There is only one other comparable model for forecasting road surface temperatures; that used by the Finnish Meteorological Office (Nysten 1980). However their model is only used to forecast up to six hours ahead, and takes much more computer time than the model proposed in this chapter.

McBean et.al. (1979) recognise the problems involved in getting boundary layer models operational:

'Boundary layer models depend on a number of ill-defined physical parameters like thermal conductivity in the soil.........and roughness height. Compromises have to be made between numerial efficiency and modelling of the physical processes in the atmosphere, in the ground and at the interface.' (page 97).

This chapter presents the alterations made to the Fortran of Outcalt's model and the presents a sensitivity analysis of the new model.

5.2 Alterations to the Fortran

1. Outcalt's 1971 model was designed to be used on cards and has 256 programme lines of which 55 are comment cards. That version of the model has been converted for interactive use by Unwin (1981) who found

that the model takes about 3 seconds of processor time (c.p.u.) on a CDC Cyber 73 computer. Unwin did not attempt to improve the model, his only changes being the presentation of S.I. units rather than the c.g.s. units of Outcalt.

In Chapter 3 of this thesis an error in the radiation generator was pointed out and 17 alterations to Outcalt's model were presented.

The following errors in Outcalt's model have also been corrected, these are more to do with Fortran and arithmetic than meteorology:

(a) Line 182 the number 57.29557 represents $180/\pi$, and should be 57.29578

(b) Line 251 INC does not represent an integer variable, and has therefore been changed to DNC

(c) Line 252 as for line 251

2. The version of the model presented in this thesis is listed in Appendix 1. It is written in standard Fortran but with the deliberate aim of making the model interactive and easy to use. Thus, for instance, instead of having to feed in the angle of declination and radius vector there are automatically calculated from the input of the day of the year (Osborne 1982). All the inputs to the model are familiar to a professional weather forecaster.

3. The interval-halving algorithm used for solving the heat balance equation for the equilibrium surface temperature in Outcalt's 1971 model has been changed to incorporate the improved method suggested by Dozier and Outcalt (1979, page 69) and used also by Greene (1980, page 5).

4. Whereas Outcalt ran his 1971 model through a two day cycle to set up the lags in the temperature profiles at depth in the ground, this model need only be run for 24 hours at 20 minute iterations. This is made possible by feeding in observed temperatures at depths of 18 cm and 36 cm in the road. This saves computation time and is obviously more accurate than using Outcalt's initial assumption of a linear temperature profile in the ground. The time interval of 20 minutes was chosen because of the 10 and 20 minutes time interval of data collection at the M4 site.

5. The actual road surface temperature at noon was taken as the starting point of the model in order to predict the minimum road temperature the following morning. Hence, Outcalt's model has been adjusted to start at noon and run for 24 hours. The calculated equilibrium road surface temperature at noon is not always exactly the same as that observed - due to the assumptions of the model. Hence, a smoothed temperature profile is calculated such that in Fortran notation:

$$TD(I) = TC(I) + (TD(I-1) - TC(I))/2.0 \qquad (5.1)$$

where TD(I) is the smoothed temperature at interval I

TC(I) is the equilibrium surface temperature at interval I

when I = 1, i.e. at noon TS(1) is set equal to the observed noon road surface temperature. Table 5.1 shows the difference between TC(I) and TD(I) for the 30 nights considered.

It can be seen from Table 5.1 that the calculated equilibrium surface temperature at noon tends to be warmer than the observed noon temperature by, on average, 1.7°C. This is probably because of the shading effect of traffic (as already discussed) or, perhaps the sky

Table 5.1

Difference Between Actual Surface Temperature and Calculated Equilibrium Surface Temperature at Noon and at Minimum

Date	TD(I)	TC(I)	ΔTD-TC	TDMin	TCMin	ΔTDMin-TCMin
31-01F79	7.5	8.4	-0.9	4.2	4.2	0.0
01-02F79	6.3	8.0	-1.7	1.8	1.7	0.1
02-03F79	8.0	7.1	0.9	-3.3	-3.3	0.0
03-04F79	6.8	10.3	-3.5	-0.7	-0.8	+0.1
04-05F79	4.3	5.5	-1.2	2.1	2.1	0.0
05-06F79	7.0	8.1	-1.1	-2.2	-2.2	0.0
06-07F79	5.9	6.1	-0.2	1.1	1.0	0.1
07-08F79	6.1	7.7	-1.6	0.3	0.3	0.0
08-09F79	4.6	4.5	0.1	1.9	1.9	0.0
09-10F79	5.5	5.1	0.4	2.3	2.3	0.0
10-11F79	5.7	4.4	1.3	1.6	1.4	0.2
11-12F79	3.3	4.2	-0.9	0.5	0.5	0.0
12-13F79	2.8	3.5	-0.7	1.0	1.0	0.0
22-23F80	8.5	9.8	-1.3	2.3	2.3	0.0
23-24F80	7.4	13.8	-6.4	1.4	1.4	0.0
24-25F80	6.5	6.6	-0.1	2.2	2.2	0.0
25-26F80	10.2	13.9	-3.7	1.7	1.6	0.1
02-04M80	13.1	21.9	-8.6	-2.8	-1.2	+0.1
04-05M80	13.1	15.6	-2.5	-1.2	-1.2	0.0
06-07M80	7.7	8.3	-0.6	4.2	4.2	0.0
07-08M80	8.2	7.9	0.3	3.6	3.6	0.0
08-09M80	7.6	11.8	-4.2	3.1	3.1	0.0
09-10M80	14.1	19.0	-4.9	3.1	3.1	0.0
10-11M80	13.4	11.2	2.2	3.1	3.0	0.1
20-21M80	9.2	11.0	-1.8	-0.2	-0.2	0.0
21-22M80	9.5	9.0	0.5	-4.4	-4.5	0.1
22-23M80	13.1	17.6	-4.5	2.5	2.5	0.0
01-02A80	12.8	13.8	-1.0	4.3	4.2	0.1
02-03A80	17.4	18.7	-1.3	4.1	4.1	0.0
03-04A90	19.5	22.3	-2.8	0.6	0.6	0.0
			$\bar{x}$ = -1.7			

view factor, which although estimated to be as high is 0.95 means that the sun does not get onto the road as soon as the model predicts.

However, Table 5.1 also shows that the difference between the predicted minima is of no consequence, i.e. TD and TC soon settle down to more or less the same temperature. The predicted temperatures will be dicussed in more detail in the next chapter.

6. In order to compare the actual road surface, air and slab temperature with the predicted equilibrium surface temperature the graphics package GINO has been used, (see pages 297-302) this program is devoted to producing the figures of the next chapter. These graphs were produced on a Hewlett Packard plotter.

Outcalt's original 1971 model has therefore been considerably extended and adapted for the purpose of predicting road surface temperatures. This model will be compared with the actual data collected on the M4 site in Chapter 6, but first the inputs to the model and the model's sensitivity to these inputs will be examined.

5.3 Inputs to the Model

Outcalt originally defined three types of data input to his model, firstly temporal data, secondly meteorological data and thirdly geographical data. Table 5.2 givesthe inputs to the new model. The geographical inputs are considered constant for the M4. The temporal inputs are averaged from data collected at the site and from nearby weather stations. Strictly speaking the air temperature, humidity and wind speed should be measured at the damping depth height, which varies each day. This is impractical as discussed in Chapter 3. Cloud information has been interpolated from observations at Heathrow Airport (50 km

Table 5.2

Inputs of the Model for Predicting Road Surface Temperatures

1. Temporal Data	(i)	Angle of declination } calculated automatically
	(ii)	Radius Vector } calculated automatically
2. Meteorological Data	(i)	Road surface temperatures at noon
	(ii)	Road sub-surface temperatures at noon at 18 cm and 36 cm
	(iii)	Wind speed at 2 m adjusted logarithmically to 20 m and averaged for 1200 → 2400 and 2400 → 1200 hours
	(iv)	Time road expected wet
	(v)	Air temperatures averaged for 5 periods: 1200 → 1500, 1500 → 1800, 1800 → 2400, 2400 → 0600, 0600 → 1200
	(vi)	Relative humidity fraction averaged for same five intervals as in (v)
	(vii)	Cloud amount and type averaged for 4 periods 1200 → 1800, 1800 → 2400, 2400 → 0600, 0600 → 1200
3. Geographical Data and Constants	(i)	Latitude 51.0°
	(ii)	Dust content 0.5
	(iii)	Thermal conductivity of concrete 4.8×10^{-3} cal/cm²/sec
	(iv)	Thermal conductivity of asphalt 3.1×10^{-3} cal/cm²/sec
	(v)	Thermal diffusivity of concrete 1.2×10^{-2} cm²/sec
	(vi)	Thermal diffusivity of asphalt 6.94×10^{-3} cm²/sec
	(vii)	Surface roughness 15 cm
	(viii)	Shadow ratio 0
	(ix)	Road damping depth 72 cm
	(x)	Air pressure 1013 mb

East) and at R.A.F. Benson for 1979, supplemented by observations from Beaufont Park (20 km South) in 1980. Tiros-N satellite pictures supplied by Dundee University have also been examined to check the movement of cloud bands.

It is not always an easy task to interpret cloud observations for a given site from nearby observations. Originally it was hoped that a net-radiometer mounted over the slab would give a direct indication of cloud cover at the M4 site. Unfortunately the radiometer would not function reliably in the road environment, without regular daily attention, which was impossible.

Outcalt does not consider cloud at all in his analysis, and he simplifies matters still further by assuming that the boundary layer air temperature and humidity do not change during the diurnal cycle. In the British climate it is inevitable that a single figure of air temperature and air humidity is misleading due to the rapid succession of air masses and frontal systems. The use of actual air temperature averaged over five time periods is obviously possible for retrospective modelling, but it inevitably creates problems for real-time forecasting as will be discussed in Chapter 7. However it does enable the model to be time dependent, and considerably improves the slope of the predicted diurnal surface temperature curve (Thornes and Roe 1981).

The model has been adapted with real-time forecasting in mind, and therefore the time intervals for the air temperature and humidity relate to the forecast periods normally used by forecasters, with the 1500 hour observation included to give an idea of the maximum air temperature.

5.4 Sensitivity Analysis - 21-22 March 1980

The purpose of this sensitivity analysis is to show the relative importance of each input to the model in respect to the forecast minimum road surface temperature. This analysis will also enable an estimation of the range of output caused by likely forecast errors in the inputs. The night of 21-22 March 1980 has been chosen for analysis as this had the coldest recorded minimum road surface temperature of the 30 nights studied (-2.8°C). For that night the inputs to the model are given in Table 5.3.

This is an interesting night for analysis, a weak cold front (no precipitation) passed over the site just before midnight, and then the cloud cleared to give considerable cooling of the road surface and the air temperature. The minimum air temperature recorded was -5.5°C, but the average air temperature from midnight to 6 a.m. was -3.8°C. The minimum road surface temperature recorded was -2.8°C. The predicted minimum road temperature is -4.4°C.

5.4.1 Damping Depth Temperature at 72 cm Below Road Surface

Table 5.4 shows that the temperature at 72 cm is directly related to the predicted minimum road surface temperature, but the effect is small. A change of 2°C in the temperature at 72 cm causes only a change of 0.1°C in the predicted minimum road surface temperature. A temperature of 9°C gives the best fit with the actual data recorded at 18 cm and 36 cm as shown in Figure 5.1. The temperature at the damping depth varies seasonally, but in winter probably only by a few degrees. The 100 cm average monthly soil temperatures for 1979/80, recorded at Reading are given in Table 5.5.

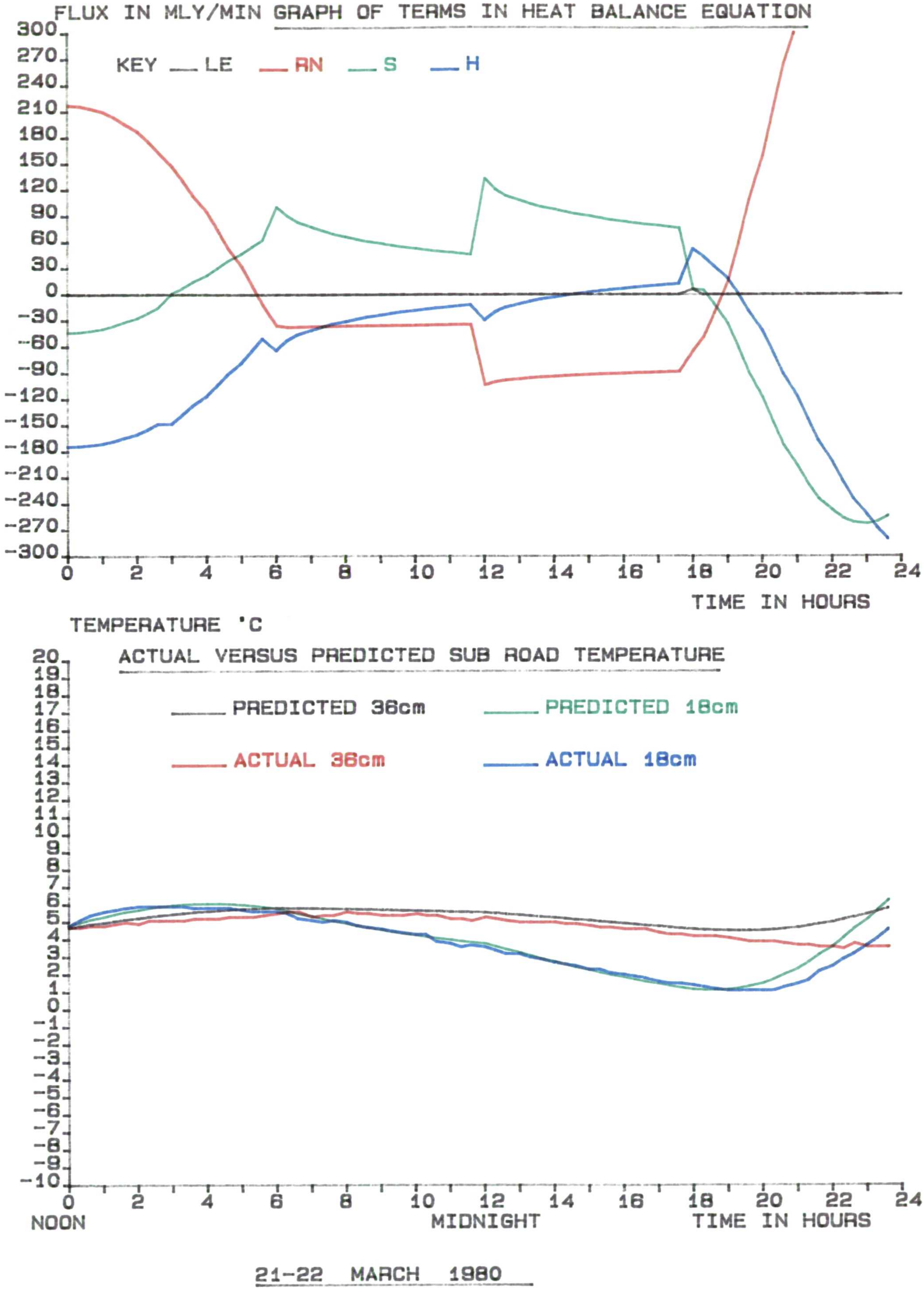


FIGURE 5.1 Actual versus predicted temperatures at 18 cm and 36 cm

Table 5.3

Inputs to Model for March 21-22, 1980

(1) Road surface temperature at noon = 9.5°C

(2) Sub-surface temperature at noon at 18 cm = 4.8°C
Sub-surface temperature at noon at 36 cm = 4.7°C
Sub-surface temperature at noon at 72 cm = 9.0°C

(3) Average wind speed 1200 - 2400 = 280 cm/sec
Average wind speed 0000 - 1200 = 136 cm/sec

		1200-	1500-	1800-	2400-	0600-
(4)	Road Dry					
(5)	Air temperature averages	2.2	1.7	-0.1	-3.8	0.6
	Relative humidity fraction	.76	.65	.71	.79	.79
		1200	1800	2400	0600	
(6)	Cloud cover average	7 LOW	6 LOW	1 LOW	2 LOW	

Table 5.4

The Effect of Road Damping Depth Temperature on Predicted Road Temperature

T72°C	Minimum Predicted °C
7.0	-4.5°C
9.0	-4.4°C
11.0	-4.3°C

Table 5.5

Mean Monthly 100 cm Soil Temperatures at Reading

Month	100 cm Soil Temperature
January 1979	5.6°C
February 1979	4.3°C
March 1979	5.1°C
April 1979	7.2°C
November 1979	10.2°C
December 1979	8.8°C
February 1980	6.2°C
March 1980	6.4°C
April 1980	8.2°C

Table 5.6

Sensitivity of the Predicted Minimum Road Surface Temperature to Wind Speed

Difference from Actual Average Wind Speed	Predicted Minimum Road Surface Temperature
-100 cm/s	-4.5°C
0	-4.4°C
+100	-4.3°C
+300	-4.1°C
+1000	-3.8°C

Table 5.7

Sensitivity of Predicted Road Temperature to Air Temperature and Humidity

		RHF+0.1	RHF	RHF-0.1
	TA+1	-3.4	-3.6	-3.7
°C	TA	-4.3	-4.4	-4.6
	TA+1	-5.2	-5.3	-5.5

RHF = Relative Humidity Fraction

Thus temperatures at these depths do not change by more than about 5°C during the winter period. This is only likely to effect minimum road surface temperatures by about ±0.25°C.

5.4.2. Wind Speed

The sensitivity of the predicted minimum road surface temperature to wind speed is shown in Table 5.6. In view of the fact that the average air temperature was -3.8°C between midnight and 0600 hours the greater the wind the more the mixing and therefore the warmer the predicted minimum road surface temperature. The relationship at these wind speeds is directly proportional such that an increase in average wind of 100 cm/s warms the road approximately by 0.1°C. Obviously the slope of this linear relationship depends upon the difference between the air and road temperatures (with a wind of +1000 cm/s the air is mixed sufficiently to make the minimum air and road temperatures equal). The wind is also important in determining the predicted diurnal range of surface temperature, this is best measured by looking at the balance temperature TC. For a wind speed of -100 cm/s the predicted diurnal range is 15.2°C, whereas for +300 cm/s it is 11.0°C, and for +1000 cm/s it is only 8.9°C.

5.4.3 Air Temperature and Humidity

The air temperature obviously has an important inter-relationship with the road surface temperature. The humidity is also important in that water vapour absorbs terrestial radiation and re-emits it back to the surface thus offsetting cooling at night. Table 5.7 shows the relative importance of these two inputs.

A difference of 1°C in the input air temperature changes the predicted minimum road surface temperature by almost the same amount, whereas a difference of relative humidity fraction of 0.1 only changes the predicted minimum by about 0.1°C.

Thus, if the forecast air temperature is wrong the predicted road minimum will also be wrong by a similar amount. However, in real time forecasting it is unlikely that all the errors in temperature prediction will be in the same direction, and hence on some occasions the errors are likely to cancel out. Experience with real time forecasting has shown that the air temperature forecasting is very important, and has led to the production of an optimistic and pessimistic road surface temperature prediction as discussed in Chapter 8.

5.4.4 Cloud Cover

Cloud is a very important input into the model in that it directly affects the radiation fluxes that drive the model. Table 5.8 shows that the difference in predicted road minimum temperature for no cloud to that for overcast all day, is only 2.6°C. The diurnal range for the no cloud situation is 25.1°C as opposed to just 9.4°C for the overcast case. Thus the greater heating associated with the lack of cloud during the day means that the minimum is not as low as one might expect. Table 5.8 also shows that the warmest minimum (-2.2°C) would have been obtained with cloud of 7/L (7/8 LOW), 6/L, 6/L, 6/L, which would allow sufficient sunshine through during the day to raise the maximum to 9.0°C and then sufficient cloud to prevent cooling beyond -2.2°C. The predicted minimum of -4.4°C with the observed cloud of 7/L, 6/L, 1/L, 2/L would have been raised to -3.4°C if the observed cloud had been 7/L. 6/L, 3/L, 3/L.

Table 5.8 The Sensitivity of the Predicted Minimum Road Surface Temperature to Cloud

		1200	1800	2400	0600	MAXIMUM	MINIMUM	RANGE
1.	Octas	8	8	8	8*	7.1	-2.3	9.4
	Height	LOW	LOW	LOW	LOW			
2.	Octas	0	0	0		20.2	-4.9	25.1
	Height	-	-	-	-			
3.	Octas	7	6	6	6	9.0	-2.2	11.2
	Height	LOW	LOW	LOW	LOW			
4.	Octas	7	6	3	3	9.0	-3.3	12.3
	Height	LOW	LOW	LOW	LOW			
5.	Octas	8	8	3	3	7.1	-3.4	10.5
	Height	LOW	LOW	LOW	LOW			
6.	Octas	7	6	1	2	9.0	-4.4	13.4
	Height	LOW	LOW	LOW	LOW			

* It must be remembered that the air temperatures are unchanged in the model for these runs, in reality with 8/8 cloud it is unlikely that the minimum air temperature would have been as low as -3.8°C.

Table 5.9 Predicted Minimum Road Surface Temperature for Different Times of the Year

Date	Predicted Minimum
21.10.79	-4.5
21.11.79	-4.6
21.12.79	-4.6
21.01.80	-4.6
21.02.80	-4.5
21.03.80	-4.4

5.4.5 Time of Year

The amount of incoming solar radiation obviously varies with time of the year. If the model is run for different months the predicted minima are as shown in Table 5.9. The differences are small for this particular example and hence the time of year is not that important. If there had been no cloud cover the differences would have been greater due to the difference in solar input. In reality the temperature at depth would be different for each month.

5.4.6 Road Wetness

The cold front that passed over the site before midnight did not produce any precipitation, and the motorway remained dry. The frost point with an air temperature of -3.8°C and a relative humidity of 79% was about -7°C, and hence there was no possibility of hoar frost being predicted by the model until 6 a.m. when the average air temperature of 0.6°C with a relative humidity of 79% gave a dew point of -3.0°C. The model then predicted hoar frost formation, with the result of 6 millilangleys/min being released for just 20 minutes when the temperature rose above -3°C. In reality, the road temperature did not fall below -2.8°C and therefore, it is unlikely that hoar frost did form that night.

If the model is run assuming a wet road from noon Figure 5.2 shows that the road temperature is predicted to fall to 0.0°C by 18.20 and remain at 0.0°C for five hours until all the moisture has turned to ice and then the surface temperature falls to -4.7°C.

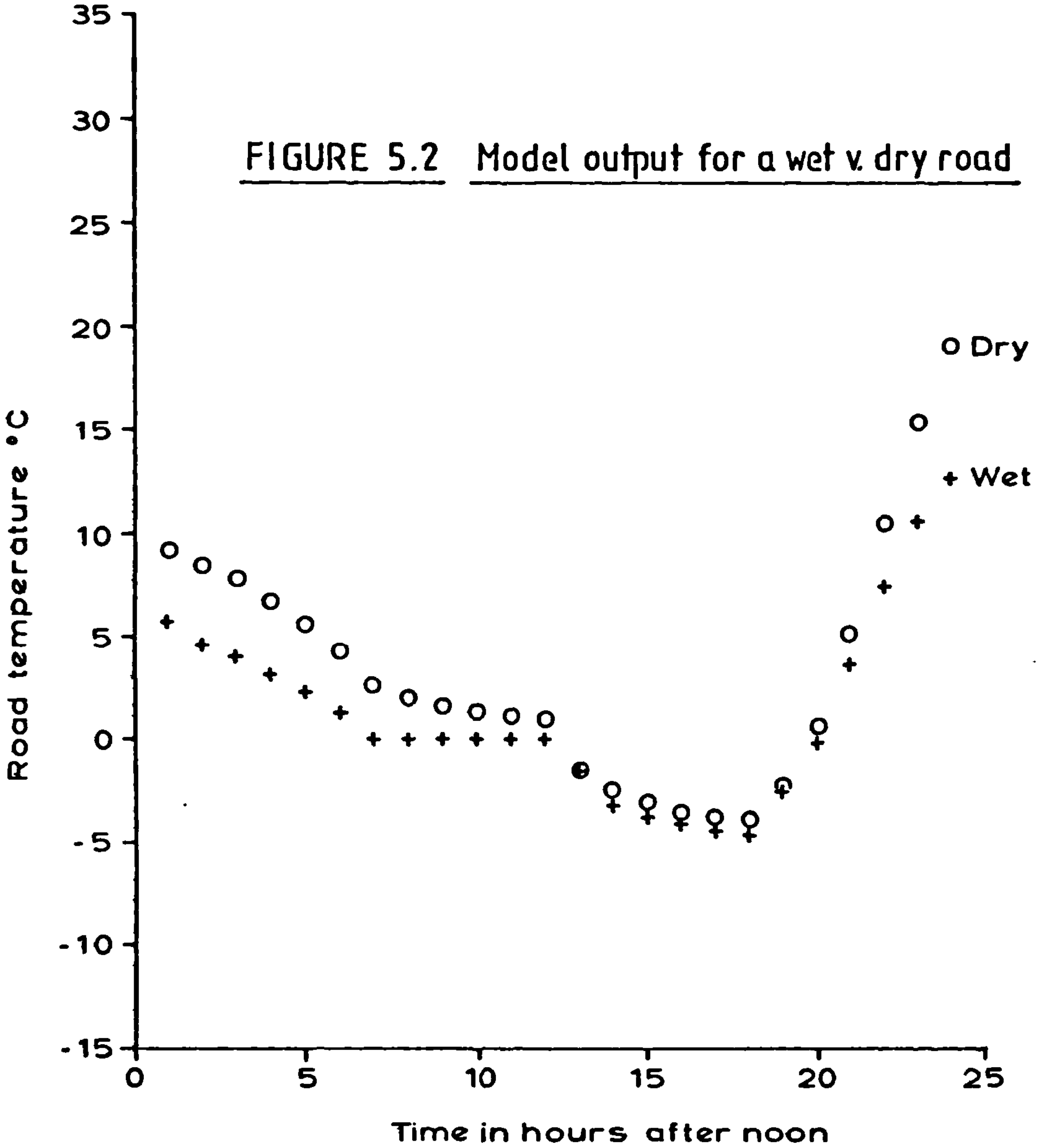


FIGURE 5.2 Model output for a wet v. dry road
o Dry
+ Wet
Road temperature °C
Time in hours after noon
35
30
25
20
15
10
5
0
-5
-10
-15
0
5
10
15
20
25

Figure 5.2 also shows that the surface temperature falls to 0.0°C much quicker on a wet road than on a dry road. This is because the water acts as an insulating layer on the road and does not allow the surface temperature to rise as high (maximum 5.4°C) as for a dry road (maximum 9.0°C), due to the heat loss via evaporation. The further cooling of the road below 0.0°C is delayed due to the release of latent heat of fusion.

The input of precipitation to the model can be selected to be one of three amounts. The above example considered that the road was covered in 1 mm of water at noon. If the model is run for less depth of water the road dries out very quickly. For 0.5 mm of water the road is predicted to dry out by 1600 hrs. and the predicted minimum is -4.1°C. For 0.15 mm of water the road is predicted to dry out by 1320 hrs., and the predicted minimum is -4.5°C. In both these two cases the model would have predicted that the road would dry out before the road surface temperature dropped to zero.

The rate at which the model predicts surface evaporation has been discussed in Chapter 3. It is based on observations of surface wetness but is still in need of further research. Nevertheless the predictions are realistic, although further improvements such as maintaining the road wet for the full 24 hours, or for precipitation at several times during the 24 hour period, are being investigated.

5.4.7 Forecasting Errors

The sensitivity analysis has shown that model prediction is most sensitive to cloud cover, wind speed and air temperature. The accuracy with which these inputs can be forecast will depend upon the synoptic situation. For instance, if the air is stable and there is little cloud, and hardly any wind, then the minimum road surface temperature will be highly dependent upon the forecast minimum air temperature. On the other hand, if it is not certain when a cold front will clear the area, then the most critical forecast might be cloud cover. On clear "radiation" nights in winter, when there is little cloud and wind, the forecaster's job is relatively straight forward. It is on occasions when cloud, wind and air temperature are all important that the model is most valuable because the relative effect of each can be seen, which makes the forecaster's job easier in difficult situations. Thus, a range of likely values can be fed into the model rather than single values. All the errors might compound to give a warmer minimum or optimistic forecast, or a colder minimum or pessimistic forecast; for instance if we take a forecast accuracy of:

UA ± 100 cm/s

TA ± 1°C   RHF ± 0.1

TH ± 0.1°C

Cloud   Front passes through to give 7/8L, 3/8L, - , -

Front delays to give   7/8L, 7/8L, 6/8L, 6/8L

(for night of 21-22 March 1980)

It must be remembered that these inputs are not independent and it is likely that if the front passes through, and the cloud completely clears, that the air temperature will be lower, and vice versa.

For a pessimistic forecast all the negative errors can be considered:

UA - 100 cm/s, TA - 1°C, RHF - 0.1, TH - 2.0°C

Cloud 7/8L, 3/8L, - , -

This gives a forecast minimum of -6.6°C. An optimistic forecast, taking all the positive errors gives a predicted minimum of -1.8°C. These two extremes give a difference in predicted minimum temperature, of 4.8°C. This is a large difference, but the probability of all the errors acting in a negative or positive way are small. It is more likely that some of the errors will be positive and some negative. This will be discussed in more detail in Chapter 8 when the problems of the use of optimistic and pessimistic forecasts for real time forecasting are dicussed.

Before a useful assessment can be made of the model for real time forecasting, it is necessary to first discuss the performance of the model in simulating retrospectively the observed road surface temperatures on the M4 motorway.

CHAPTER 6 ACTUAL VERSUS PREDICTED ROAD SURFACE TEMPERATURES

6.1 Introduction

The Fortran model outlined in the last Chapter has been tested retrospectively against the 30 nights observed road surface temperatures discussed in Chapter 4. The actual versus predicted minimum road surface temperatures are given in Table 6.1 and shown in Figure 6.1. The mean absolute error is 0.65°C, and the root mean square error is ±0.87°C. The model was accurate to within ±1.0°C on 23 of the 30 nights. Therefore retrospectively the model is accurate to within a degree centigrade for approximately 75% of the time. Each of the 30 nights will now be considered briefly before a full discussion of the results is made. It must be remembered that not all of the inputs to the model were observed, and that the model might be even more accurate retrospectively if, for instance, cloud values had been observed at the actual site.

6.2 Night by Night Analysis of Model Performance

For each of the 30 nights considered the following information is presented in Appendix 2:

(i) An infra-red satellite picture (TIROS-N) taken during the early afternoon of the 24 hour period considered. These satellite photographs have been kindly supplied by the Electronic Laboratory of the University of Dundee.

(ii) The mid-day synoptic chart for the start of the 24 hour period. The charts are taken from 'weather log' published in the journal, Weather.

Table 6.1

Actual Versus Predicted Minimum Road Surface Temperatures

Date	Actual Minimum °C	Actual Minimum Time	Predicted Minimum °C	Predicted Minimum Time	ΔT_{A-P} °C	Time <0°C Actual	Time <0°C Predicted
31-01F79	3.9	(2100 hr)	4.2	(2340)	-0.3		
01-02F79	1.1	(0800)	1.8	(0720)	-0.7		
02-03F79	-2.4	(0400)	-3.3	(0540)	+0.9	2320	2400
03-04F79	-0.8	(2320)	-0.7	(0540)	-0.1	2320	2040
04-05F79	2.3	(0240)	2.1	(0540)	+0.2		
05-06F79	-1.9	(0440)	-2.2	(0540)	+0.3	2400	0020
06-07F79	2.2	(0220)	1.1	(2340)	+1.1		
07-08F79	-0.6	(0740)	0.3	(0720)	-0.9	0600	
08-09F79	1.5	(0540)	1.9	(0420)	-0.4		
09-10F79	2.2	(0120)	2.3	(2320)	-0.1		
10-11F79	1.4	(2300)	1.6	(1500)	-0.2		
11-12F79	0.6	(0540)	0.5	(0700)	+0.1		
12-13F79	2.1	(0120)	1.0	(2320)	+1.1		
22-23F80	2.4	(0440)	2.3	(0540)	+0.6		
23-24F80	1.7	(0140)	1.4	(0540)	+0.3		
24-25F80	2.7	(0400)	2.2	(0640)	+0.5		
25-26F80	2.0	(0040)	1.6	(0540)	+0.4		
03-04M80	-0.5	(0520)	-2.8	(0540)	+2.3	0420	0040
04-05M80	0.4	(0440)	-1.2	(0540)	+1.6		0040
06-07M80	3.6	(0500)	4.2	(0300)	-0.6		
07-08M80	3.0	(0100)	3.6	(0540)	-0.6		
08-09M80	3.0	(0300)	3.1	(0540)	-0.1		
09-10M80	4.2	(0120)	3.1	(0540)	+1.1		
10-11M80	3.0	(0300)	3.1	(0540)	-0.1		
20-21M80	-0.3	(2400)	-0.2	(0540)	-0.1	2400	2120
21-22M80	-2.8	(0540)	-4.4	(0540)	+1.6	2340	0000
22-23M80	3.0	(0340)	2.5	(0520)	+0.5		
01-02A80	3.4	(0400)	4.3	(0520)	-0.9		
02-03A80	4.1	(0300)	4.1	(0520)	0.0		
03-04A80	2.5	(0540)	0.6	(0540)	+1.9		

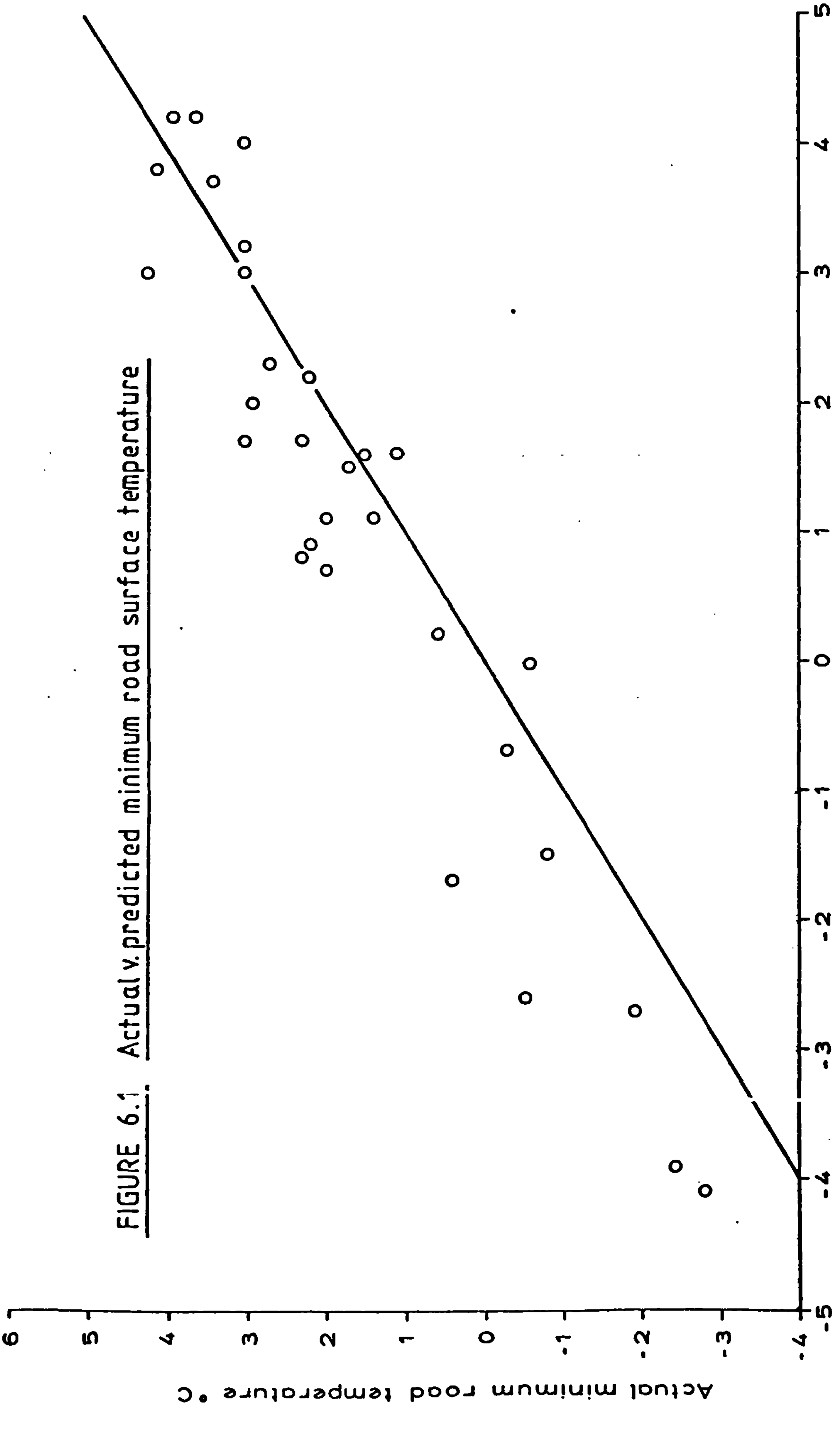


FIGURE 6.1 Actual v. predicted minimum road surface temperature

(iii) The actual observed temperature data is given at 20 minute intervals for the 24 hour period.

Column 1: the motorway surface temperature; TO

Column 2: the temperature at 36 cm below the road surface; T36

Column 3: the air temperature at 2 m; Air

Column 4: the temperature at 18 cm below the road surface; T18

Column 5: the slab surface temperature. Tslab

(iv) The output from the model is given in ten columns which represent 20 minute predictions of:

Column 1 : Solar Time, the first three rows all contain 12.00, these represent 12.00, 12.20, and 12.40 hours respectively;

Column 2 : Sun, the predicted amount of solar radiation arriving at the road surface;

Column 3 : RN, the predicted net radiation at the surface, which is positive during the day time, and negative at night;

Column 4-5: S, the predicted heat exchange with the road structure below the road surface;

Column 5 : H, the predicted heat exchange with the air;

Column 6 : LE, the predicted amount of evaporation, condensation or sublimation;

Column 7 : TD, the adjusted predicted road surface temperature. The temperature at noon is adjusted to the actual observed road surface temperature at that time;

Column 8 : TC, the calculated equilibrium surface temperature;

Column 9 : Sum, the accumulated amount of latent heat - used to calculate when the road dries out;

Column 10: RI, Richardson's number, for a neutral profile the values should be within the range ±0.01.

(v) A plot of the predicted heat balance. At any one time the sum of the components equals zero.

(vi) A plot of the actual versus predicted temperatures at 18 cm and 36 cm. If the curves are well matched this means that the damping depth temperature in the road has been well chosen.

In the text a plot of actual versus predicted road surface temperatures is included to show not only the performance of the model as a predictor of the minimum motorway temperature, but also to show how well the model has predicted the diurnal curve. This is important to compare the actual versus predicted times when the motorway surface temperature falls below 0°C. The observed air temperatures and slab temperatures are also plotted for comparison. The input data to the model is also given above the actual versus predicted graphs. The inputs are self explanatory except that UA1, and UA2 are the average wind speeds at 20 m for the times 1200 - 2359, and 0000 - 1159 hours respectively; and the TIME WET is given as a number between 1 and 24, representing 0100 to 2400 hours respectively. A value of 0 means that the road was dry. The angle of declination and radius vector are for the last hour of the 24 hour period. The model calculates hourly values but only stores the latest value, and the graph is produced by the computer after the calculations have been completed.

1. 31st January - 1st February 1979

A frontal system giving rain by 2200 hours spread in from the west. The satellite pictures confirm that there was extensive cloud over the region throughout the night and therefore the diurnal range of the road temperature was only 5.1°C. Figure 6.2 shows that the predicted road surface temperature is very close to the actual throughout the day. The plots of actual versus predicted temperatures at 18 cm and 36 cm are also in good agreement as shown in Appendix 2. The heat balance shows that during the night the road was losing heat via net radiation, evaporation and conduction to the sub-road, and this was balanced by heat gained from the air. The model also predicts that the road would have dried out by about 1100 hours on the morning of the first of February as the frontal system moved away into Europe. Rainfall figures at Benson show however that any drying out was short lived as a complex area of low pressure moved in on the afternoon of the 1st February to give more rain.

2. 1st February - 2nd February 1979

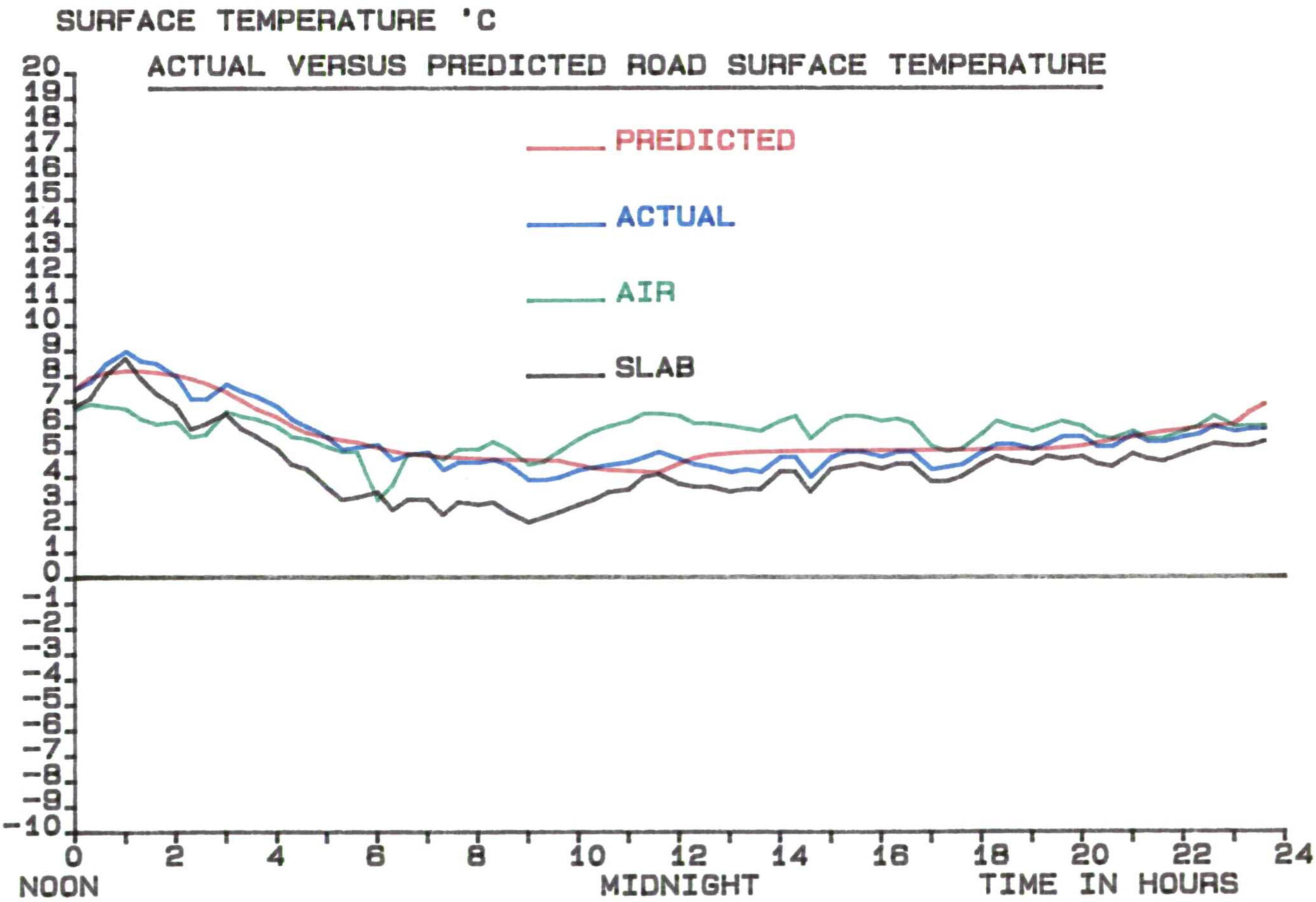
A small but complex low pressure system crossed the area during the day bringing quite heavy rainfall. Eventually the cloud cleared and the road temperature dropped to 1.1°C as high pressure pushed in from the north west. Figure 6.3 shows that the predicted curve follows closely the actual curve, and that the slab temperature dropped off quickly after about 0500 hours, as the cloud cleared, to drop just below 0°C. This could have been a dangerous situation had the road temperature dropped another degree in that the road was still wet after the earlier heavy rain. The model predicted a minimum of 1.8°C on a wet road which it predicted to dry out by about 1000 hours.

DATE: <u>31-01 FEBRUARY 1979</u> FIGURE 6.2

DEC: -17.20 R: .985

BOUNDARY CONDITIONS: UA1, UA2: 435.0 688.0 TIME WET: 22

	1200	1500	1800	2400	0600
TO'C	7.5				
T18'C	2.8				
T36'C	2.2				
TA'C	6.3	5.7	5.1	6.0	5.9
RHF	.78	.83	.89	.89	.91
CLOUD	7		7	8	8
	LOW		LOW	LOW	LOW

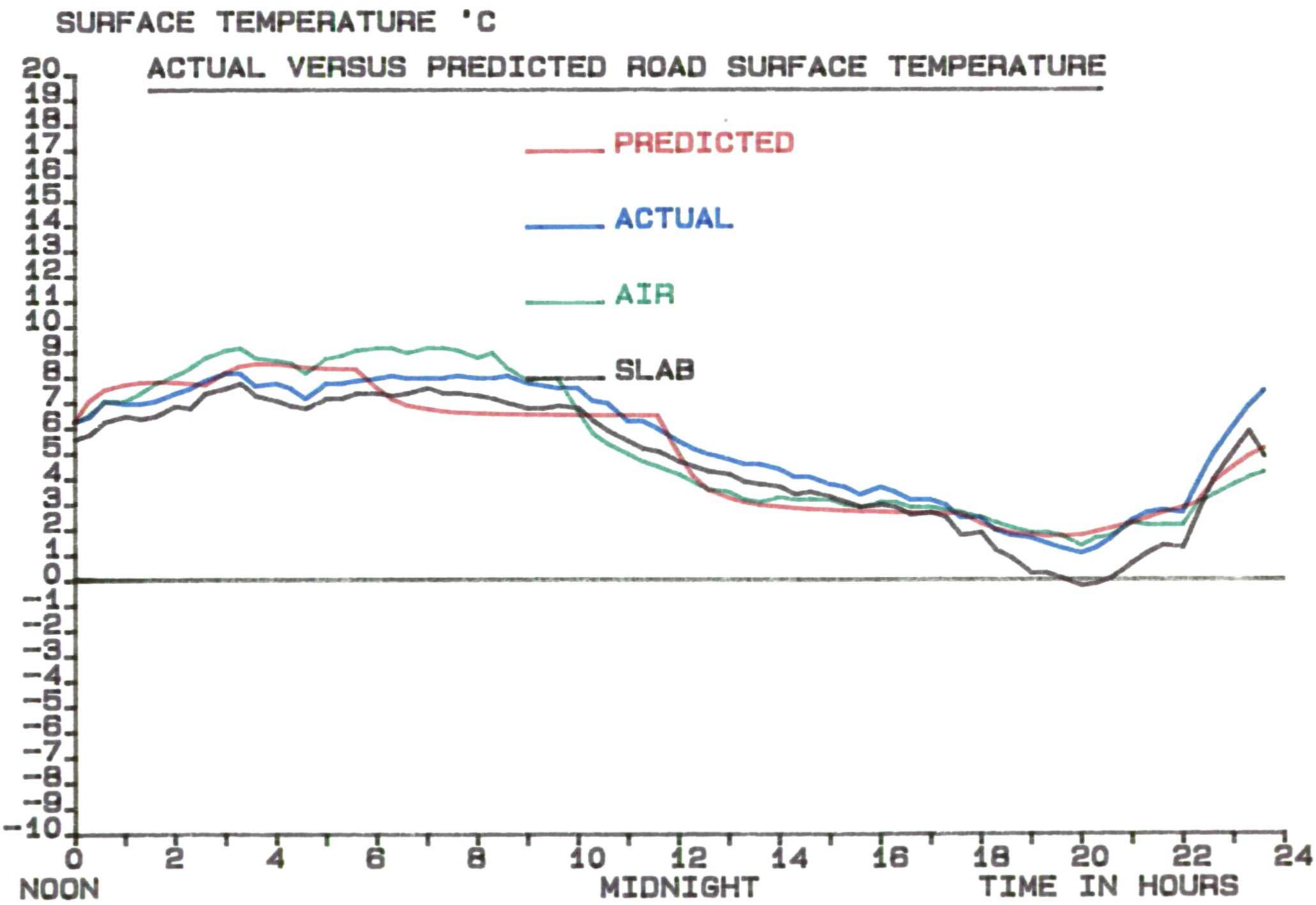


DATE: 01-02 FEBRUARY 1979 FIGURE 6.3

DEC: -16.91 R: .986

BOUNDARY CONDITIONS: UA1, UA2: 573.0 709.0 TIME WET: 12

	1200	1500	1800	2400	0600
TO'C	6.3				
T18'C	4.9				
T36'C	4.0				
TA'C	7.5	8.8	7.6	3.2	2.5
RHF	.95	.99	.88	.89	.87
CLOUD	8		8	8	3
	LOW		LOW	LOW	LOW



The predicted 18 cm and 36 cm temperatures are very good. The predicted heat balance is complicated in that, due to a high wind, evaporation was high most of the night which meant that heat from both the air and the sub-road was needed to balance the evaporation. Note that condensation was predicted to occur between 1600 hours and 1800 hours when the road temperature dropped below the average air temperature. In reality that was unlikely as the air temperature did drop below the road temperature briefly as shown in Figure 6.3. However, the model uses average air temperatures rather than actual air temperatures.

3. 2nd February - 3rd February 1979

The ridge of high pressure established itself for the 24 hour period and the road surface cooled steadily all day. The sky was totally clear from just before midnight to about 0700 hours, however the road remained dry and in view of the fact that the road was warmer than the air, hoar frost formation was not a danger. The predicted road temperature (Figure 6.4) is within an hour of the actual road temperature falling below 0°C. However, the predicted minimum is 0.9°C below the actual minimum.

With a dry road the heat balance is less complicated with the heat flux to the ground and air balancing the net radiation. The predicted temperatures at 18 cm and 36 cm are very good.

4. 3rd February - 4th February 1979

The high pressure was gradually squeezed out and rather weak slow moving fronts approached from the west to bring in plenty of cloud but no rain. Again the road temperature fell to zero just before midnight

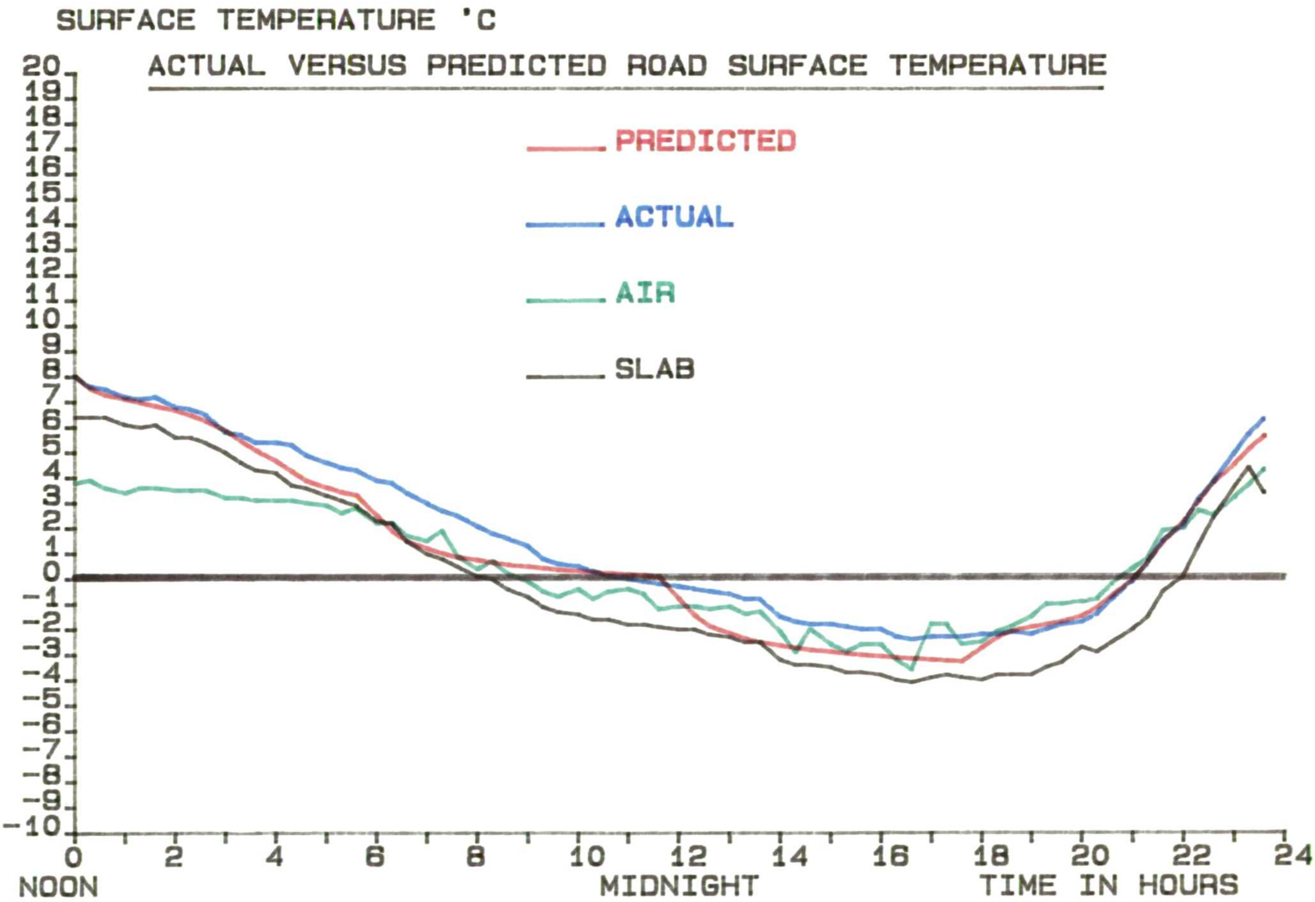
DATE: 02-03 FEBRUARY 1979

FIGURE 6.4

DEC: -16.62 R: .986

BOUNDARY CONDITIONS: UA1, UA2: 316.0 289.0 TIME WET: 0

	1200	1500	1800	2400	0600
TO'C	8.0				
T18'C	4.2				
T36'C	4.1				
TA'C	3.6	3.0	.4	-2.1	.5
RHF	.59	.56	.83	.86	.78
CLOUD	7		3	0	1
	LOW		LOW		HIH



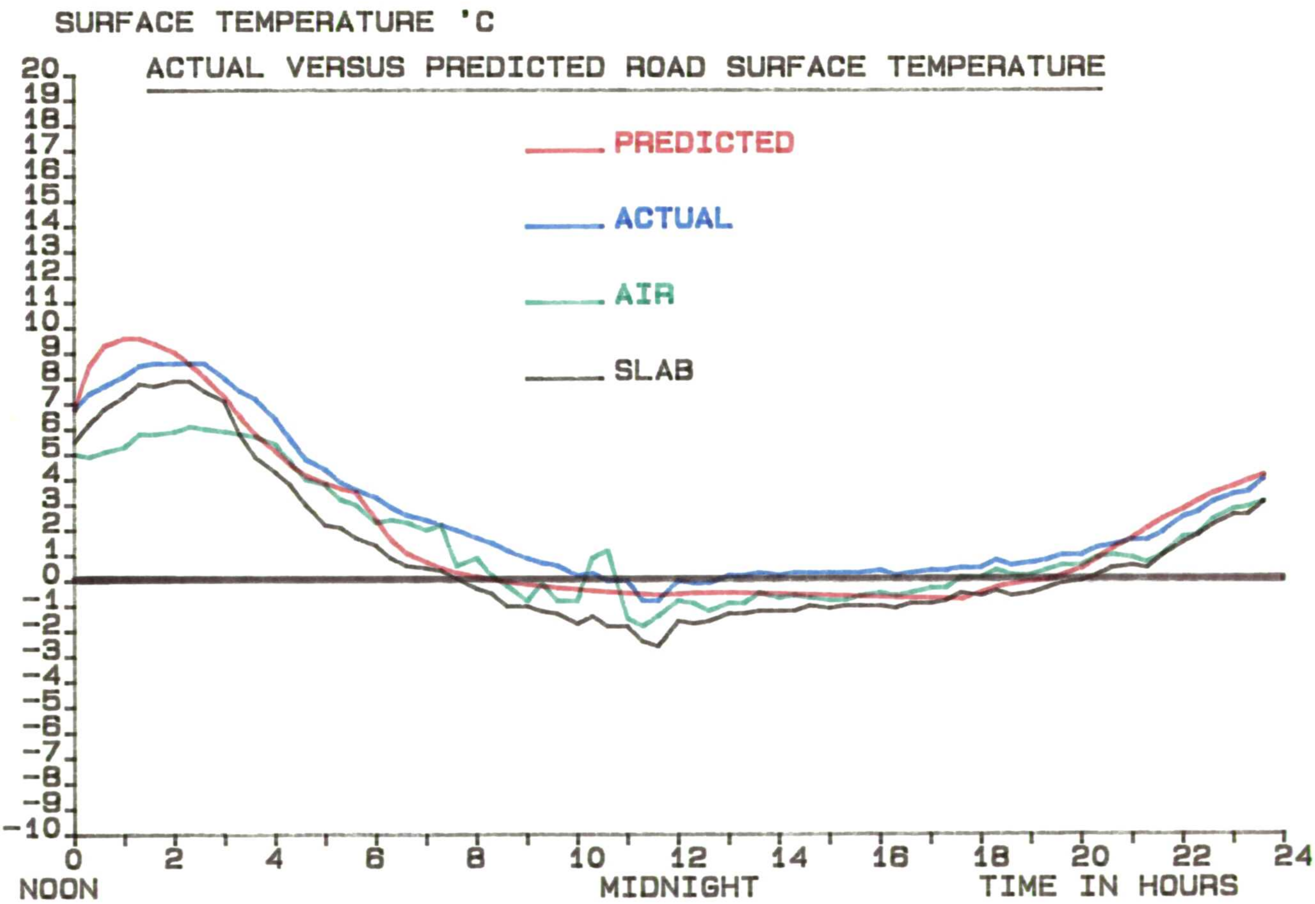
DATE: 03-04 FEBRUARY 1979

FIGURE 6.5

DEC: -16.33 R: .986

BOUNDARY CONDITIONS: UA1, UA2: 352.0 155.0 TIME WET: 0

	1200	1500	1800	2400	0600
TO'C	6.8				
T18'C	2.3				
T36'C	2.6				
TA'C	5.5	4.6	.4	-.6	1.2
RHF	.60	.66	.81	.81	.79
CLOUD	1		1	7	8
	LOW		LOW	LOW	LOW



(figure 6.5) but the cooling below zero was short lived as the cloud moved across. The model predicts an earlier fall to zero but the estimate of the minimum temperature is very good. There was no danger of hoar frost formation with such cold dry air, and the sudden air warming just before midnight was short lived. The heat balance is dominated by exchange with the sub-road, as with little wind the heat exchange with the air was small. Predicted temperatures at 18 cm and 36 cm are again very good.

5. 4th February - 5th February 1979

An overcast day with only a small diurnal range of the motorway surface temperature of 4.6°C, as weak, almost stationary fronts dominated. The temperatures at 18 cm and 36 cm hardly changed all day and the heat balance is very straight forward. The road temperature began to pick up late in the morning as the cloud eventually started to clear The model appears to behave well in overcast conditions (Figure 6.6).

6. 5th February - 6th February 1979

High pressure pushed down over the country from the north and the sky cleared completely in the early evening. The predicted curve is excellent, not only in the predicted minimum but also in the time of fall of road temperature velow 0°C. The air temperature was very similar to road temperature and with a steady continuous breeze mixing was sufficient to prevent the road cooling below the air temperature with the clear sky. The predicted 18 cm and 36 cm curves are very good and the heat balance is again straight forward. The slab minimum was -4.5°C which was 2.6°C colder than the road (Figure 6.7).

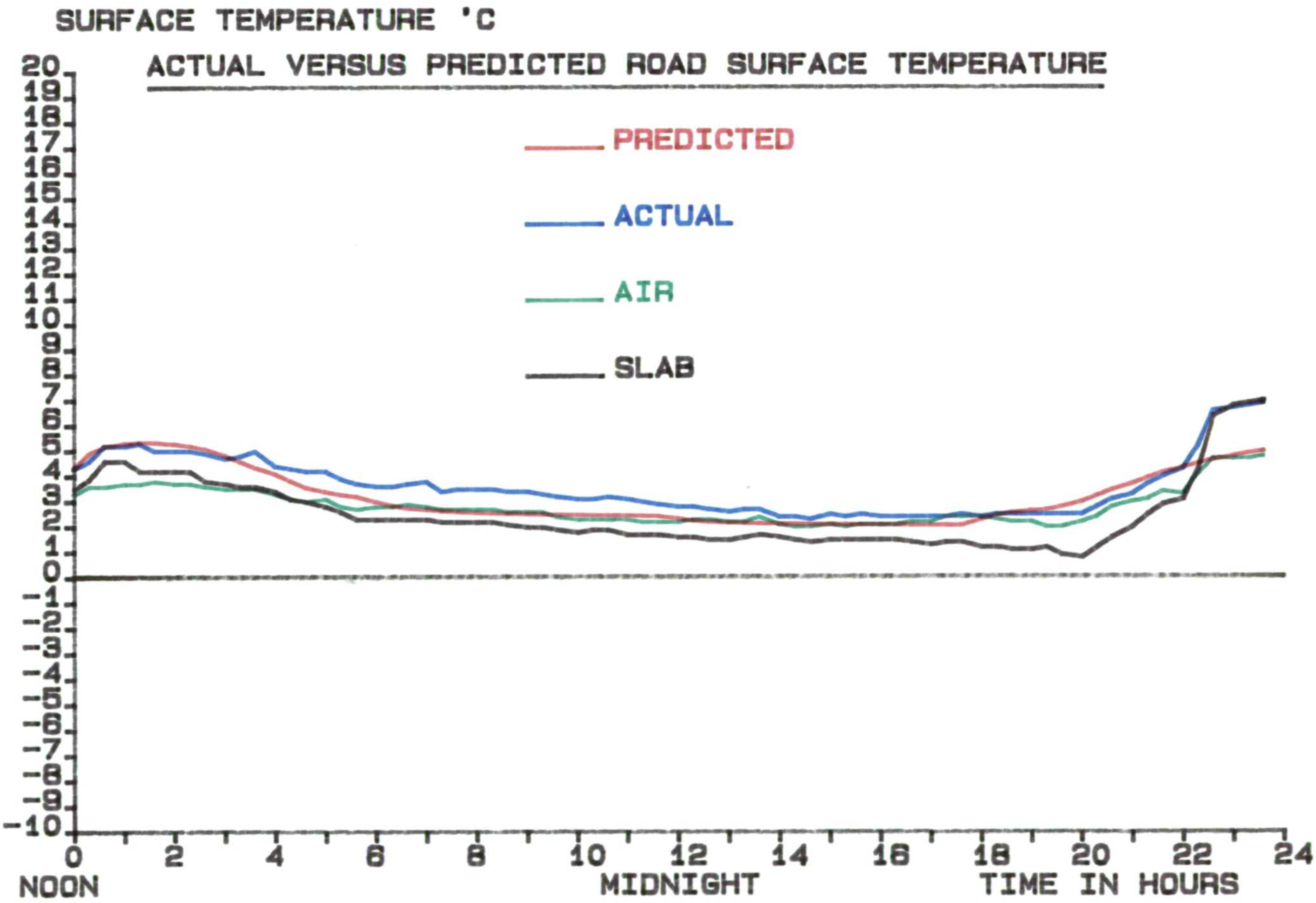
DATE: 04-05 FEBRUARY 1979

FIGURE 6.6

DEC: -16.03 R: .986

BOUNDARY CONDITIONS: UA1, UA2: 533.0 522.0 TIME WET: 0

	1200	1500	1800	2400	0600
TO'C	4.3				
T18'C	2.6				
T36'C	2.6				
TA'C	3.6	3.2	2.6	2.2	3.1
RHF	.81	.76	.80	.87	.91
CLOUD	8		8	8	8
	LOW		LOW	LOW	LOW



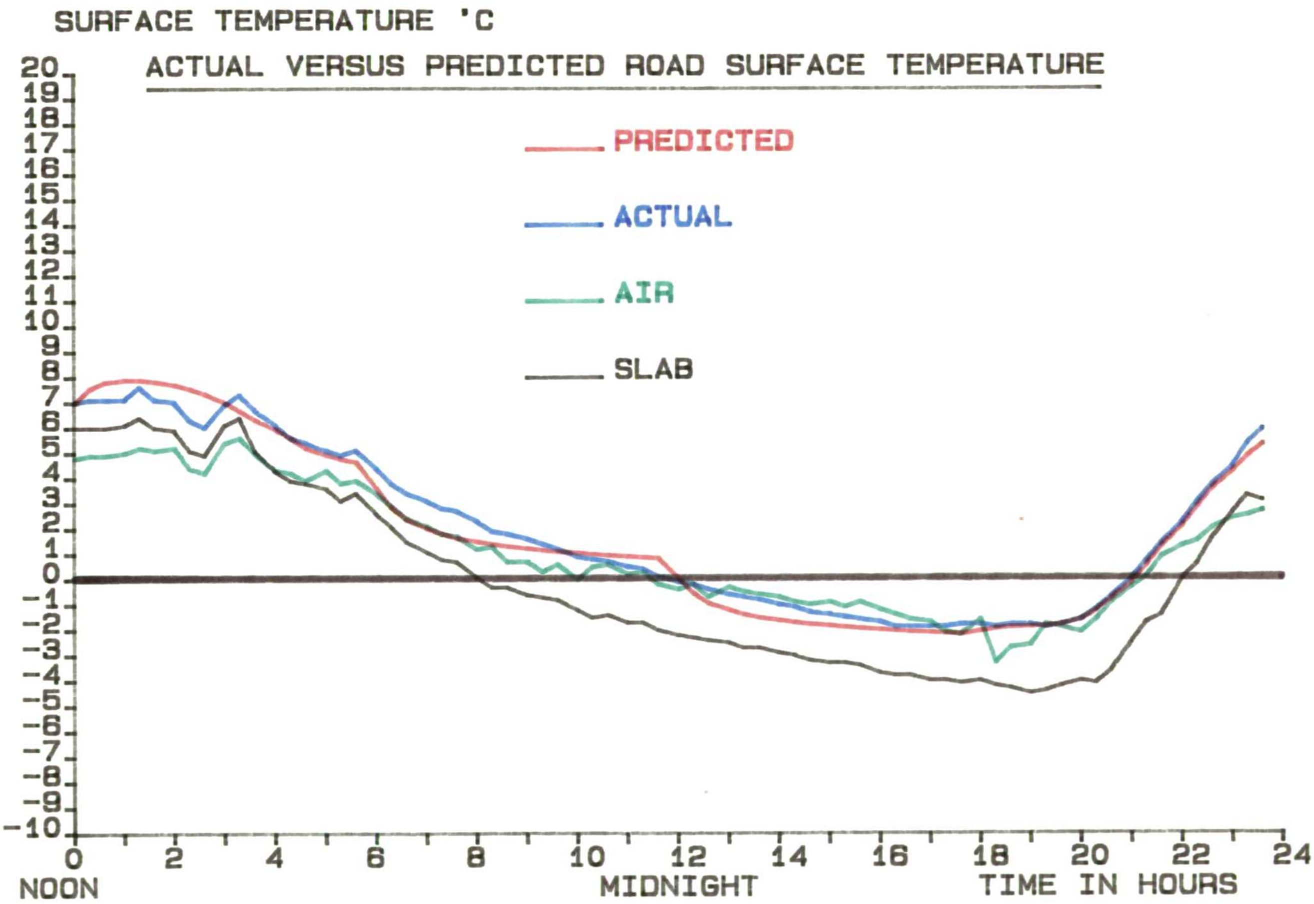
DATE: 05-06 FEBRUARY 1979

FIGURE 6.7

DEC: -15.72 R: .986

BOUNDARY CONDITIONS: UA1, UA2: 361.0 331.0 TIME WET: 0

	1200	1500	1800	2400	0600
TO'C	7.0				
T18'C	4.4				
T36'C	3.5				
TA'C	4.9	4.5	1.1	-1.0	-.3
RHF	.82	.78	.90	.89	.80
CLOUD	7		3	0	1
	LOW		LOW		HIH



The cloud and wind were almost identical to the night of the 2nd/3rd February, and there was only 0.5°C difference in the actual minimum road temperature.

7. 6th February - 7th February 1979

Overcast conditions returned as an occluded front moved in from the south west bringing rain and sleet from 2200 hours onwards. The road temperature remained well above zero however and the predicted curve is about a degree too cold for much of the night (Figure 6.8). The temperatures at 18 cm and 36 cm hardly changed at all, but as the occluded front went through the air temperature gradually rose. The heat balance shows that slight condensation is predicted around 0600 hours when the air and road temperatures converged, but in reality probably evaporation just went down to zero as the humidity increased to about 100%.

8. 7th February - 8th February 1979

This is an interesting night for analysis as the thick layer of strato cumulus that overlayed the area broke up in the early hours of the morning to give sudden cooling and a road surface minimum temperature of -0.6°C (Figure 6.9). The air minimum did drop to -0.1°C but only for about 20 minutes. The predicted curve only falls to +0.3°C but from Figure 6.9 it can be seen that because of the average cloud cover of 5/8 low from midnight until 0600 hours, and because sunrise was at just after 0700 hours the model did not have sufficient time to cool the road to 0.0°C. This is a problem with using average cloud, air temperatures and wind speeds. When the cloud cleared the wind also dropped so that the use of an average cloud of 5/8 low and an average

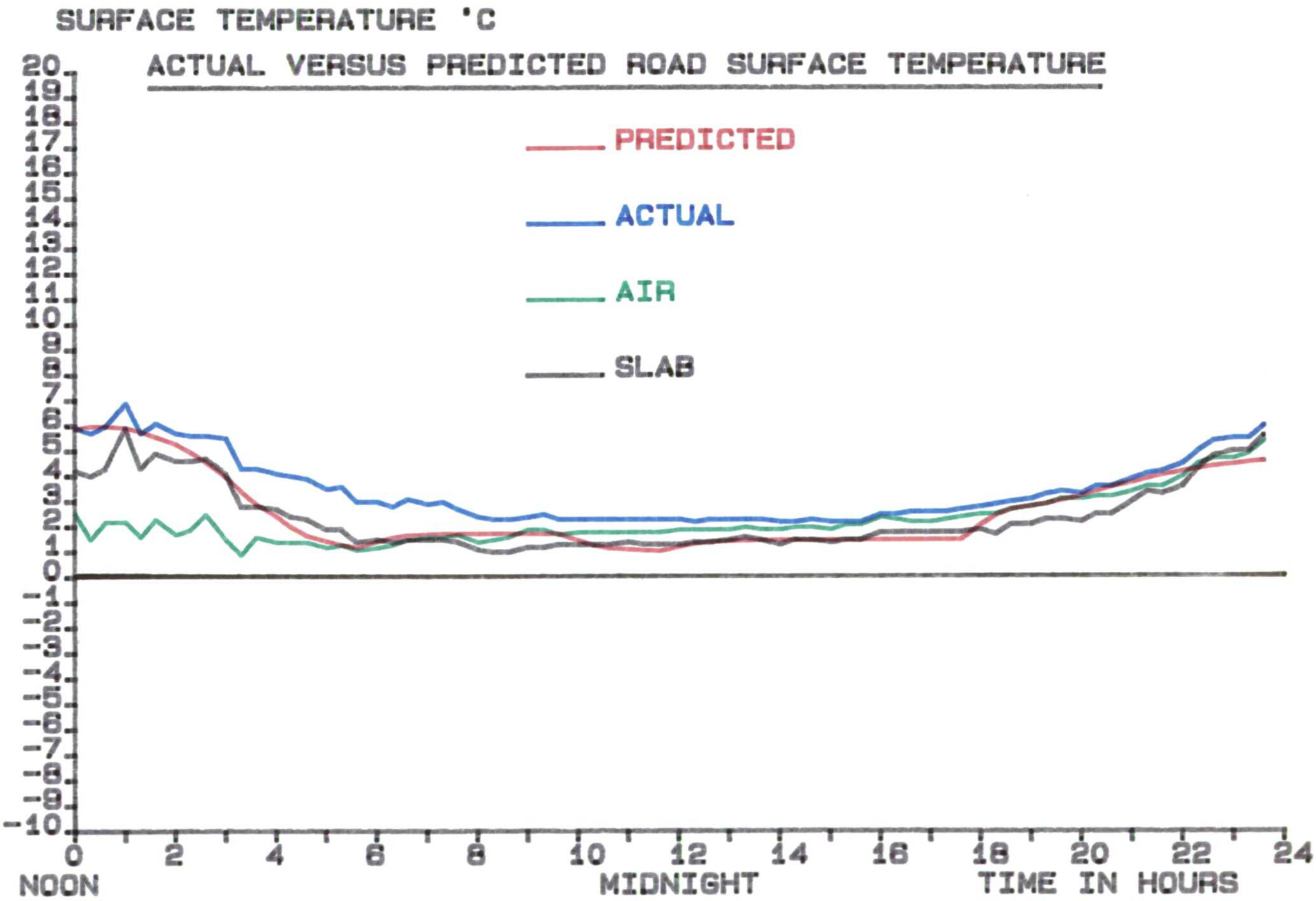
DATE: 06-07 FEBRUARY 1979

FIGURE 6.8

DEC: -15.41 R: .986

BOUNDARY CONDITIONS: UA1, UA2: 758.0 478.0 TIME WET: 22

	1200	1500	1800	2400	0600
TO'C	5.9				
T18'C	2.2				
T36'C	2.6				
TA'C	2.0	1.3	1.7	2.1	3.6
RHF	.66	.81	.87	.92	.97
CLOUD	5		8	8	8
	MED		LOW	LOW	LOW



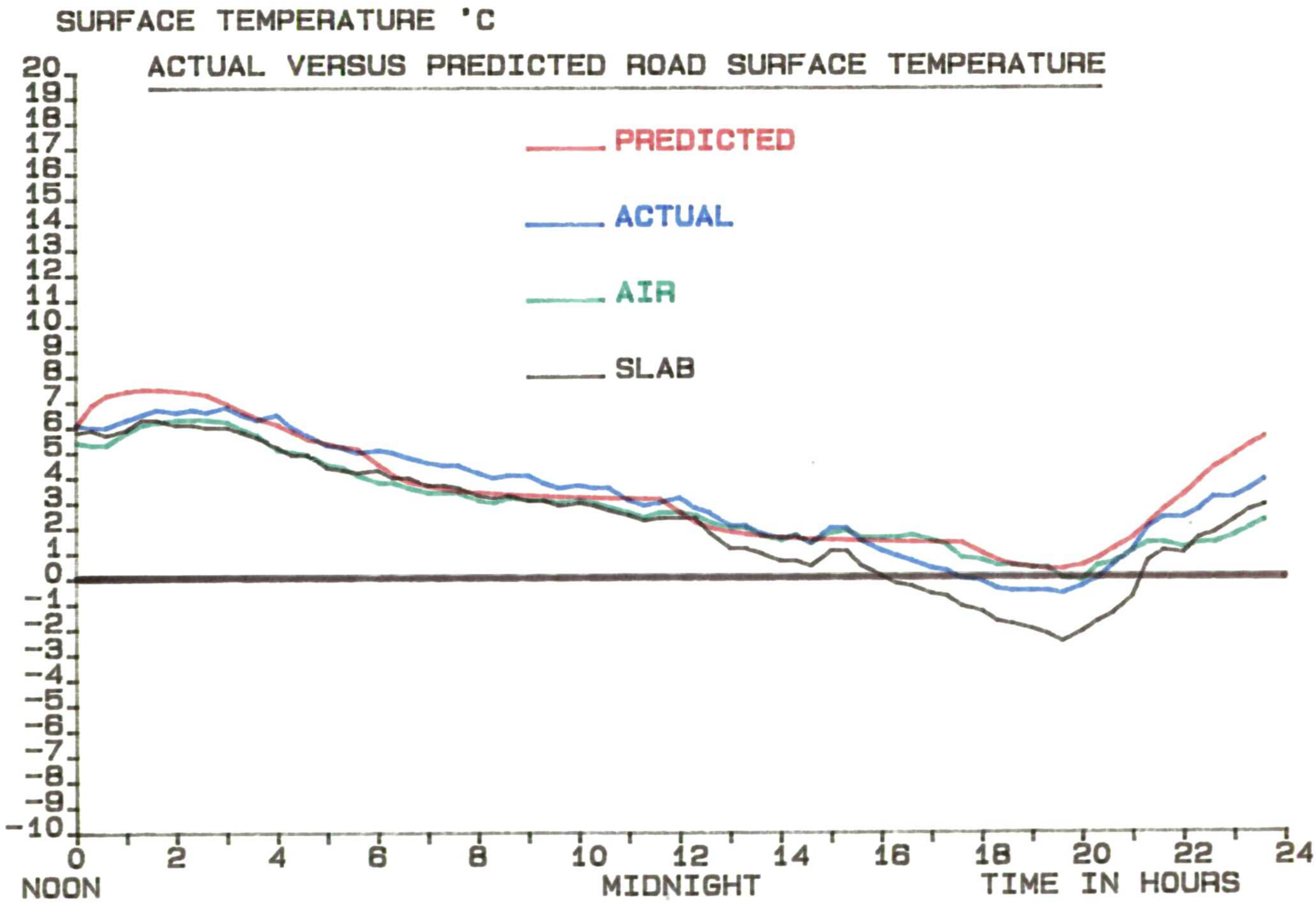
DATE: 07-08 FEBRUARY 1979

FIGURE 6.9

DEC: -15.10 R: .986

BOUNDARY CONDITIONS: UA1, UA2: 599.0 607.0 TIME WET: 0

	1200	1500	1800	2400	0600
TO'C	6.1				
T18'C	4.0				
T36'C	3.4				
TA'C	5.9	5.1	3.1	1.7	1.0
RHF	.97	.95	.91	.85	.80
CLOUD	8		8	5	1
	LOW		LOW	LOW	HIH



wind of 607 cm/s is misleading. If the model is run again with just 1/8 low after midnight the predicted minimum (TC) drops to -0.2°C. Also, if the average wind for midnight to 0600 hours is dropped to 400 cm/s the predicted minimum falls to -0.1°C. This shows the value of feeding in a range of input values rather than just one value for real time forecasting. It also suggests that, rather than use average values for the six hour periods, perhaps a linear extrapolation should be used. For instance, if the cloud at midnight is 8/8 low and by 0600 hours is 1/8 low then obviously it would be better to use 8/8 low at just after midnight decreasing linearly until 1/8 low is reached just before 0600 hours. Linear extrapolation of air temperature is being used for real time forecasting in the West Midlands as discussed in Chapter 8.

This night represents a 'classic' example of the road temperature taking a sudden dip (when the cloud clears) due to radiational cooling. The air temperature does not cool so quickly in these circumstances, as it lags behind the cooling of the ground in the absence of advection.

The temperatures at 18 cm and 36 cm did not change much during the day, but the predicted curves are both too warm by the end of the day, due to the non prediction of the temperature drop.

9. and 10. 8th February - 9th February and 9th February - 10th February 1979

Both days were overcast throughout with a weak occluded front more or less stagnant over south west England. The diurnal range on the 8th-9th was only 4.2°C and that on the 9th-10th only 3.8°C (Figures 6.10 and 6.11). On both days the predicted diurnal curve is fine and the temperatures at 18 cm and 36 cm hardly changed at all. In these overcast situations forecasting is easy! The winds were very strong averaging

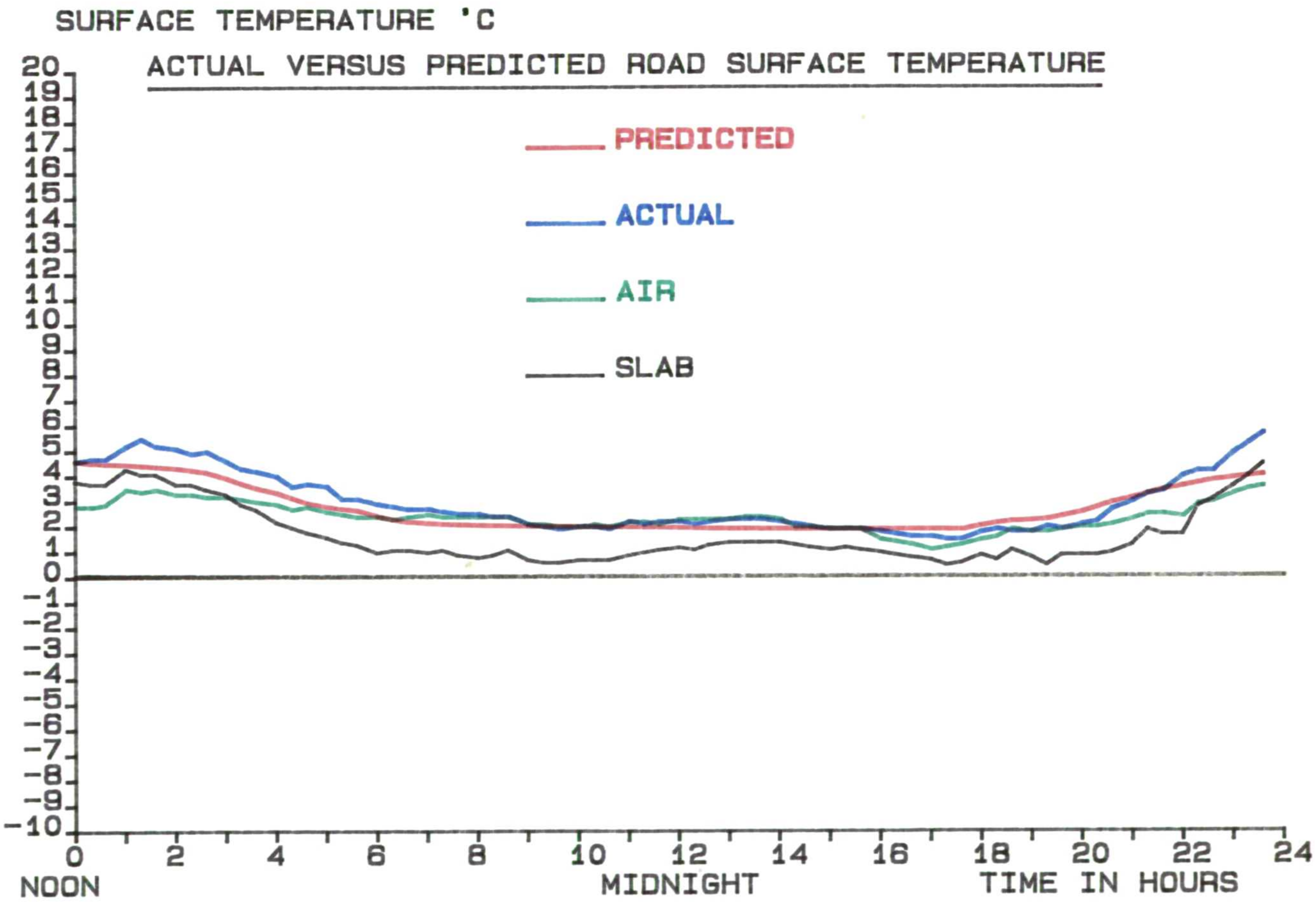
DATE: 08-09 FEBRUARY 1979

FIGURE 6.10

DEC: -14.78 R: .987

BOUNDARY CONDITIONS: UA1, UA2: 898.0 826.0 TIME WET: 0

	1200	1500	1800	2400	0600
TO'C	4.6				
T18'C	2.7				
T36'C	2.7				
TA'C	3.2	2.8	2.2	1.9	2.4
RHF	.68	.68	.76	.71	.75
CLOUD	8		8	8	8
	MED		MED	LOW	LOW



DATE: 09-10 FEBRUARY 1979

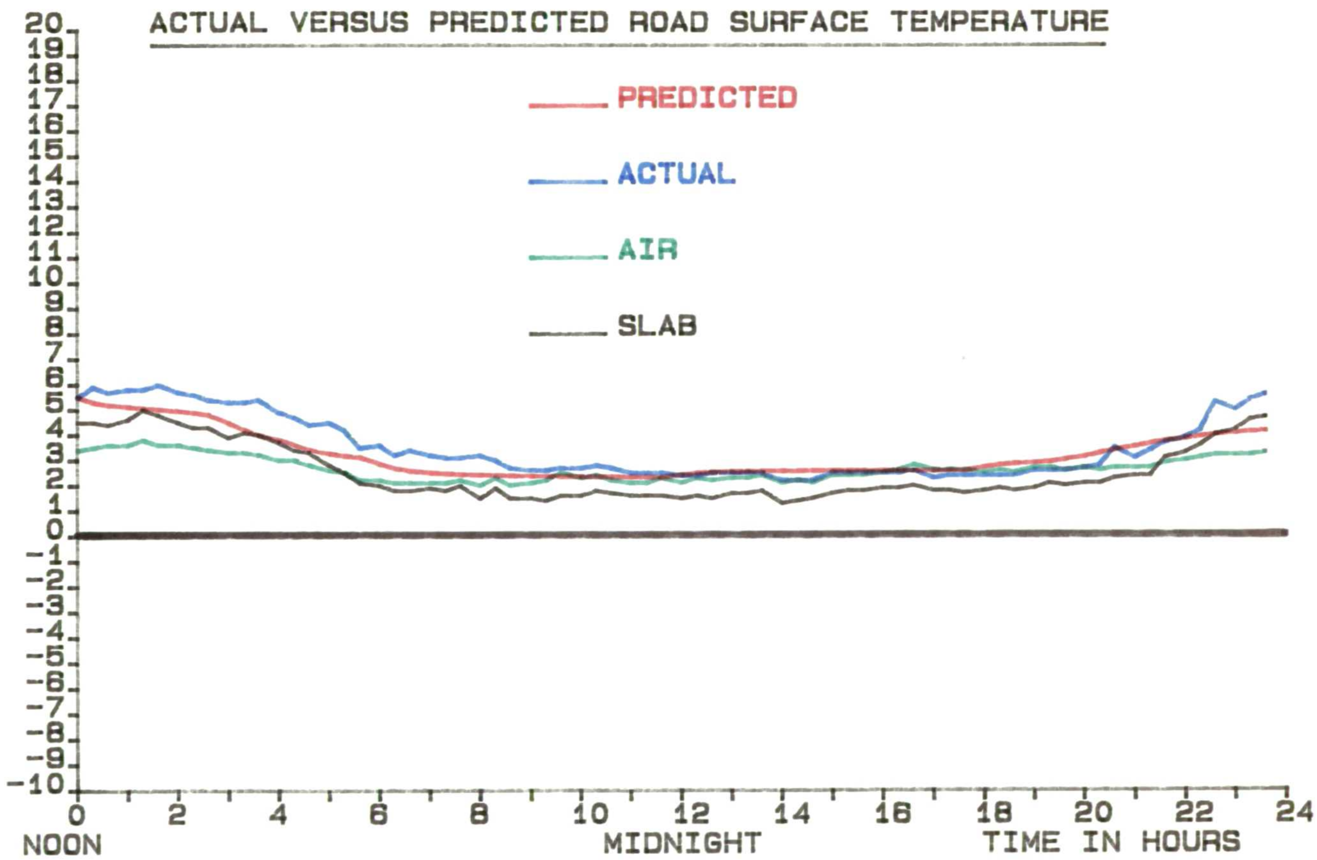
FIGURE 6.11

DEC: -14.46 R: .987

BOUNDARY CONDITIONS: UA1, UA2: 1077.01395.0 TIME WET: 0

	1200	1500	1800	2400	0600
TO'C	5.5				
T18'C	3.2				
T36'C	3.0				
TA'C	3.6	2.9	2.2	2.4	2.8
RHF	.88	.85	.86	.86	.87
CLOUD	8		8	8	8
	LOW		LOW	LOW	LOW

SURFACE TEMPERATURE 'C



over 1000 cm/s on the 9th-10th, and this ensured that there was very little difference at night between the air and road temperatures due to mixing.

11. 10th February - 11th February 1979

Very strong easterly winds ensured again that the air and road temperatures were similar for much of the night. There was a trace of rain during the afternoon which, due to the excessive wind, gave tremendous evaporation for a short period until the road was again dry. The model assumes that all the precipitation falls at the same time which is obviously not true, and the dip in road temperature predicted by the model during the afternoon shows that the model is over estimating the effect of such a small amount of rain. Nevertheless, the model predicts a rise in temperature as the road dries out, returning to the actual surface temperature (Figure 6.12). The temperatures at 18 cm and 36 cm hardly change at all during the day.

12. 11th February - 12th February 1979

A developing depression over Northern France moved northwards and brought rain and sleet by 2000 hours. It remained overcast throughout the night but the wind did lead to some cooling around dawn due to the advection of cold air from the east. The wind dropped during the night but gradually the road temperature followed the air temperature. The actual minimum of 0.6°C with a wet road led to a full salting of the M4 at around 0400 hours. This is the nearest night to the possibility of ice formation of the 30 nights considered. The predicted model minimum of +0.5°C relects well the actual conditions (Figure 6.13).

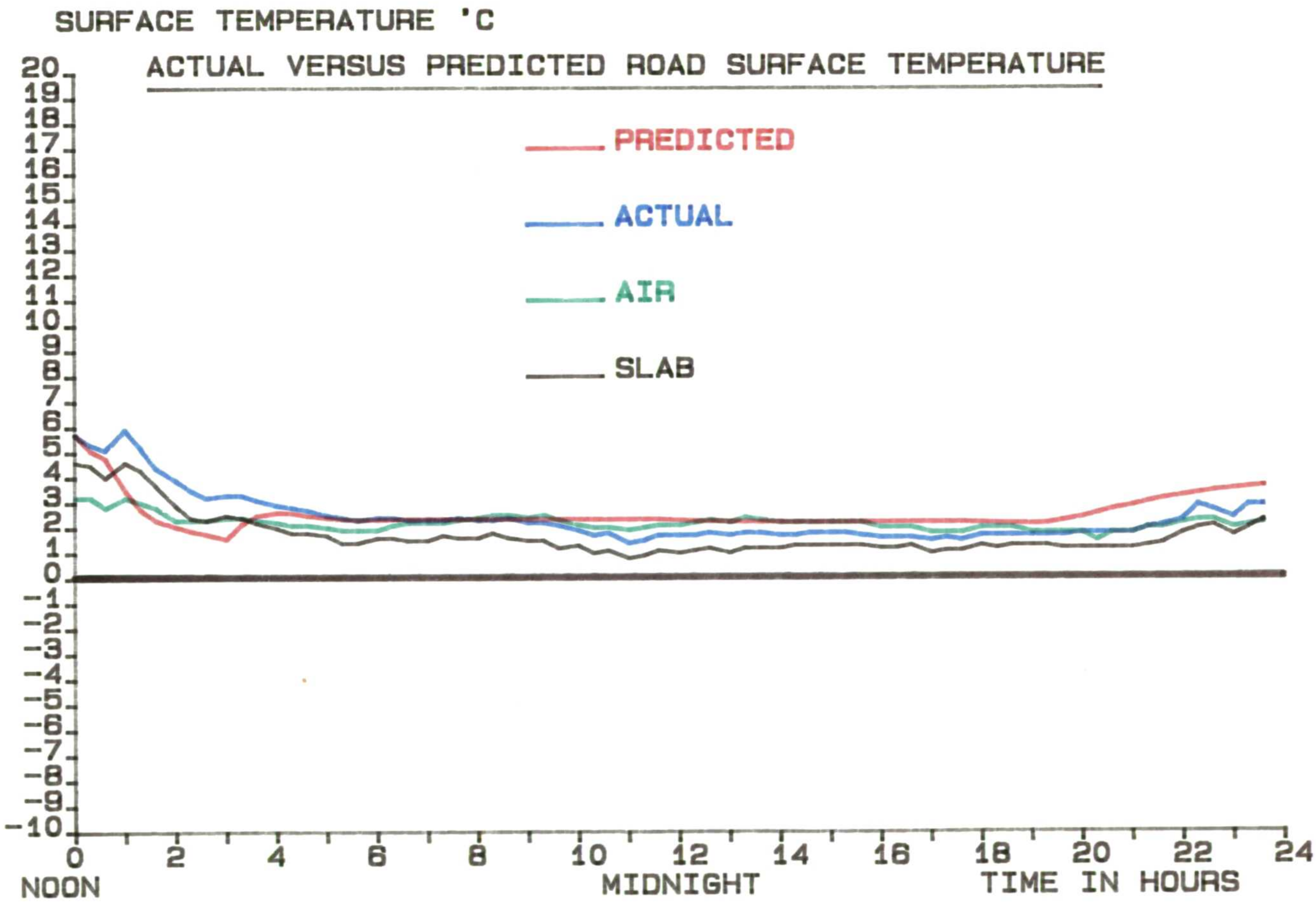
DATE: 10-11 FEBRUARY 1979

FIGURE 6.12

DEC: -14.14 R: .987

BOUNDARY CONDITIONS: UA1, UA2: 1089.01021.0 TIME WET: 13

	1200	1500	1800	2400	0600
TO'C	5.7				
T18'C	3.7				
T36'C	3.4				
TA'C	2.8	2.1	2.2	2.1	2.0
RHF	.66	.72	.78	.79	.83
CLOUD	8		8	8	8
	LOW		LOW	LOW	LOW



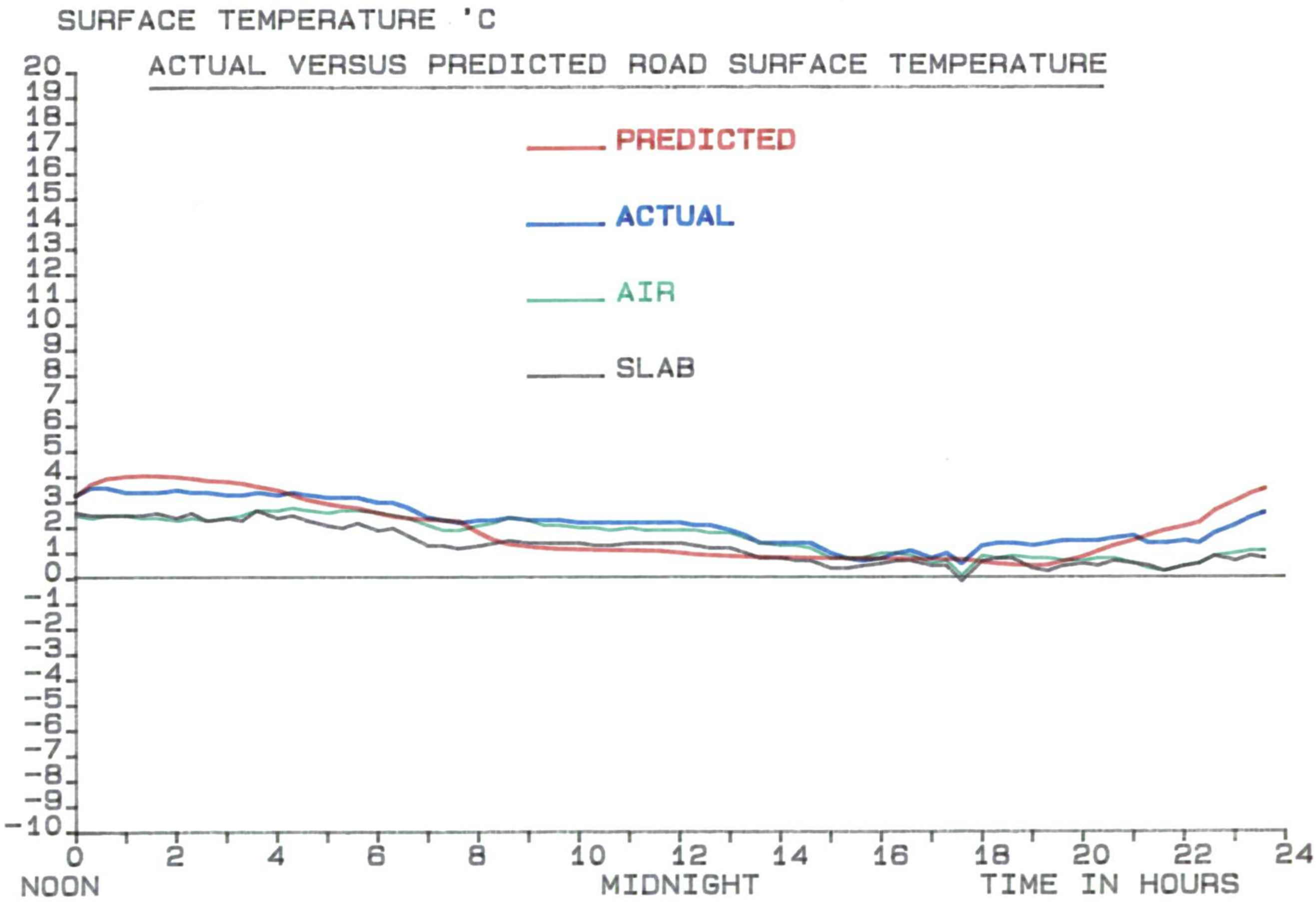
DATE: 11-12 FEBRUARY 1979

FIGURE 6.13

DEC: -13.81 R: .987

BOUNDARY CONDITIONS: UA1, UA2: 868.0 296.0 TIME WET: 20

	1200	1500	1800	2400	0600
TO'C	3.3				
T18'C	2.7				
T36'C	3.1				
TA'C	2.4	2.6	2.1	1.2	.8
RHF	.82	.84	.81	.94	.95
CLOUD	8		8	8	8
	LOW		LOW	LOW	LOW



13. 12th February - 13th February 1979

Again an overcast day with some rain and sleet throughout the day. The road temperature remained above 2.0°C all night (Figure 6.14), but the motorway was salted. The air temperature gradually increased as the day went on. The sub-road temperatures hardly changed all day and due to the overcast sky and light winds the heat balance is small.

14. 22nd February-23rd February 1980

Heavy rain fell during the afternoon as a double cold front moved west to east across the area, pushed by a ridge of high pressure extending north-eastwards. The peak in the air, road and slab temperatures between 1500 and 1600 hours suggests that there was a thin wedge of warmer air between the two cold fronts. The predicted curve is cooler than the actual road temperature for much of the night but only by about 1°C (Figure 6.15). The predicted temperatures at 18 cm and 36 cm are very good and the heat balance is straight forward with evaporation being reduced as the night continued due to less wind and high humidity.

15. 23rd February - 24th February 1980

Low pressure over the English Channel kept a fair amount of cloud over the region. The air temperature did drop just below 0.0°C at 0200 hours in the morning but the road minimum temperature was 1.7°C. The predicted maximum temperature was about 3°C too high but otherwise the model performs well (Figure 6.16). The air temperature might have continued to fall but for the formation of fog due to the high humidity. Because the road was about 3°C warmer than the air the heat balance shows that the road was in fact losing heat to the air from midnight

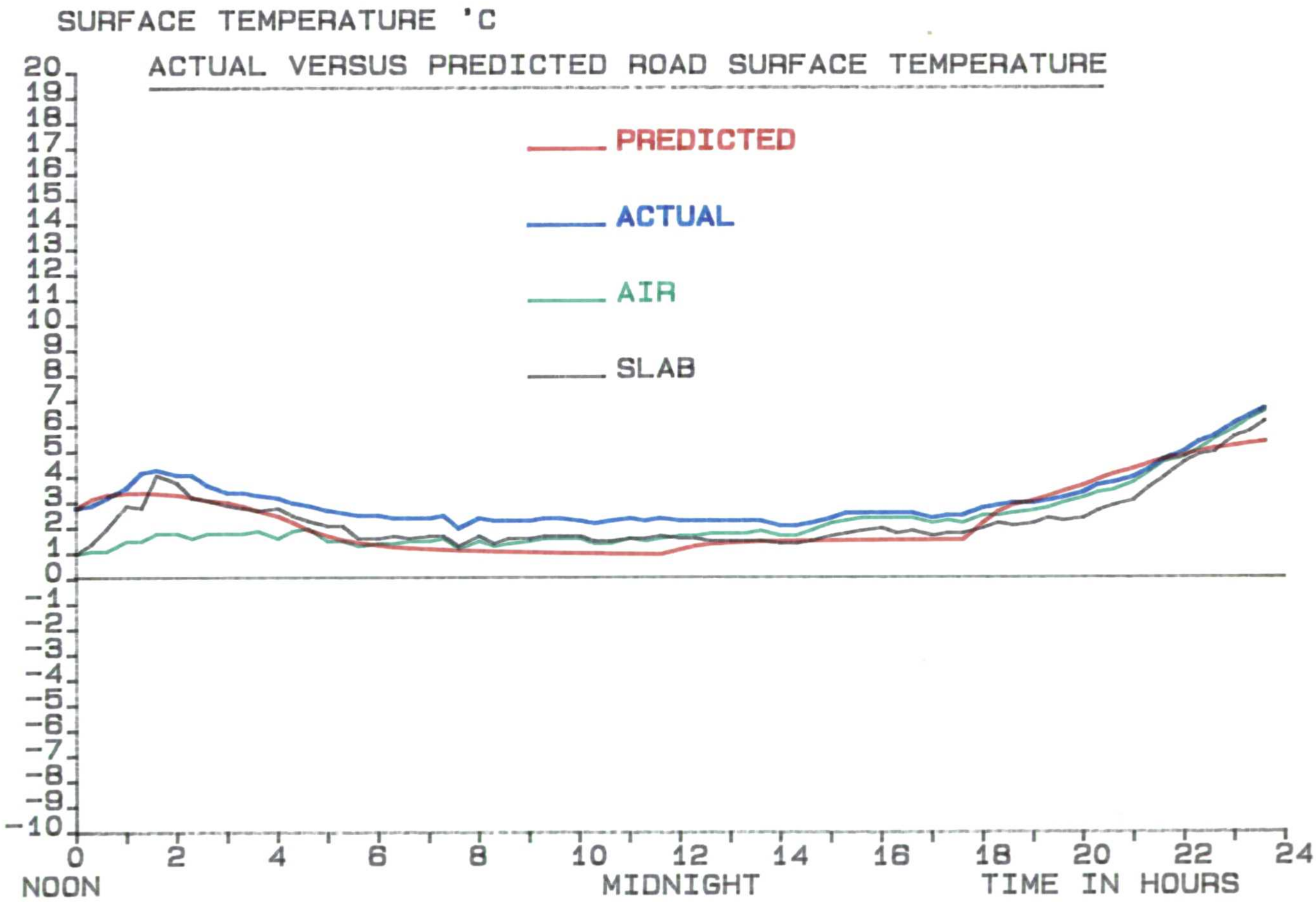
DATE: 12-13 FEBRUARY 1979

FIGURE 6.14

DEC: -13.47 R: .987

BOUNDARY CONDITIONS: UA1, UA2: 248.0 354.0 TIME WET: 12

	1200	1500	1800	2400	0600
TO'C	2.8				
T18'C	2.4				
T36'C	2.9				
TA'C	1.5	1.7	1.5	2.0	4.1
RHF	.92	.92	.94	.96	.98
CLOUD	8		8	8	8
	LOW		LOW	LOW	LOW



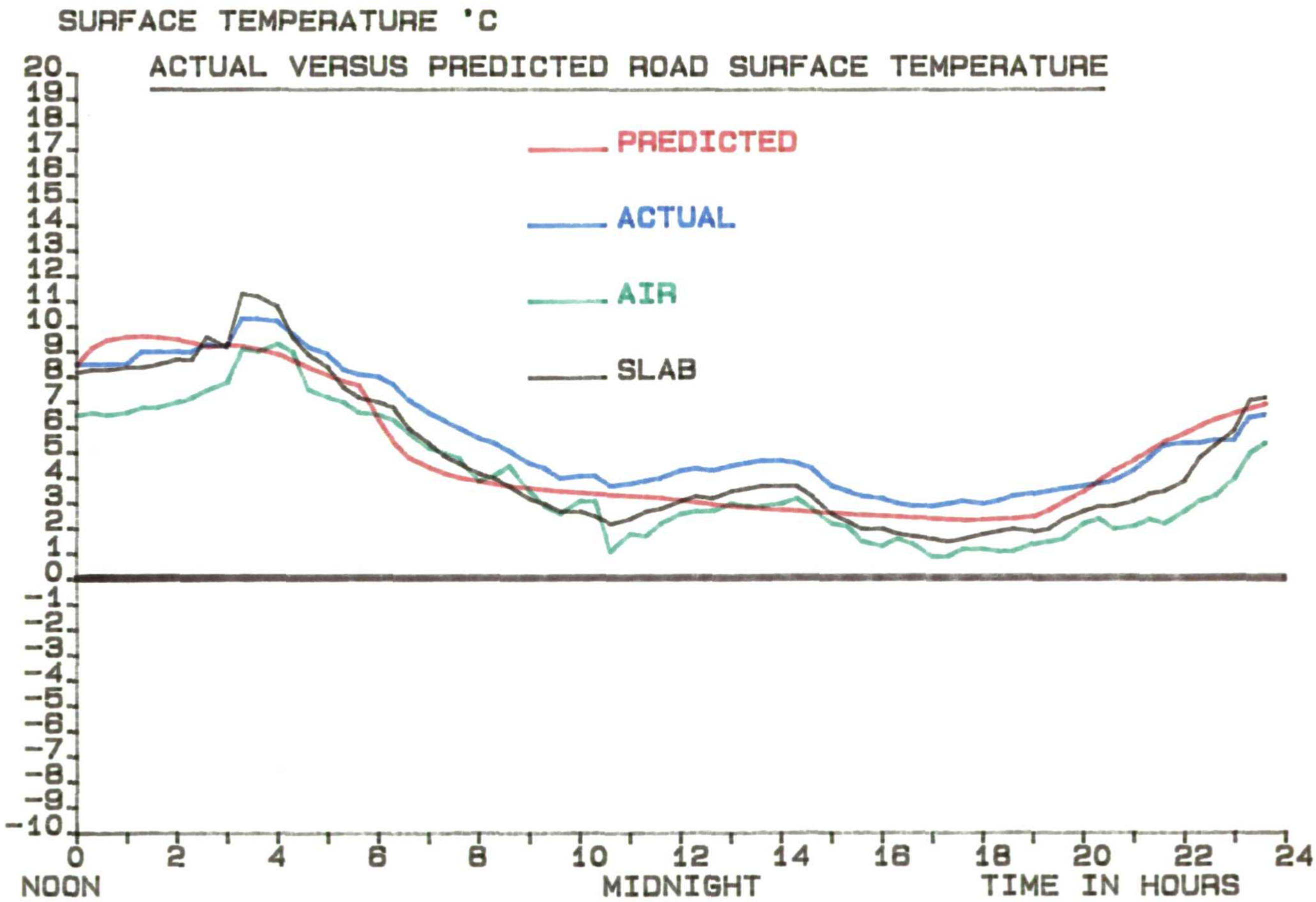
DATE: 22-23 FEBRUARY 1980

FIGURE 6.15

DEC: -10.04 R: .989

BOUNDARY CONDITIONS: UA1, UA2: 232.0 70.0 TIME WET: 12

	1200	1500	1800	2400	0600
TO'C	8.5				
T18'C	8.8				
T36'C	8.4				
TA'C	6.8	8.1	3.8	2.2	2.5
RHF	.94	.90	.90	.92	.94
CLOUD	7		5	6	8
	LOW		LOW	LOW	LOW



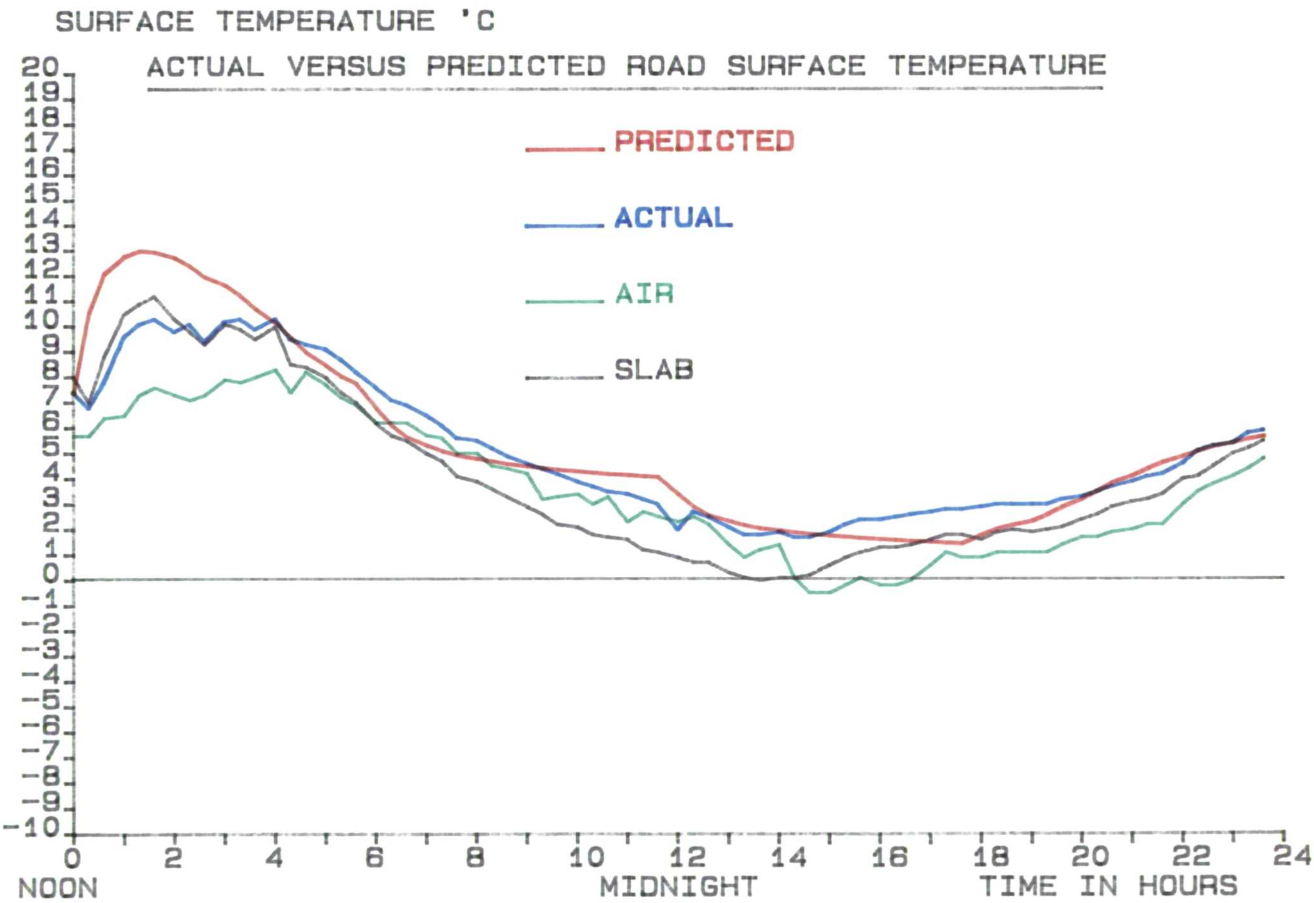
DATE: 23-24 FEBRUARY 1980

FIGURE 6.16

DEC: -9.68 R: .990

BOUNDARY CONDITIONS: UA1, UA2: 336.0 360.0 TIME WET: 0

	1200	1500	1800	2400	0600
TO'C	7.4				
T18'C	5.8				
T36'C	6.9				
TA'C	6.8	7.7	4.3	.7	2.3
RHF	.83	.68	.81	.98	.96
CLOUD	5		3	6	8
	LOW		LOW	LOW	LOW



to 0600 hours. The predicted temperatures at 18 cm and 36 cm are a little distorted due to the high predicted maximum temperature, but overall the prediction is fair.

16. 24th Febraury - 25th February 1980

A thick layer of stratus remained until about midnight when the cloud cleared slightly, as the band of cloud then associated with a low to the south east, moved northwards. The predicted curve shows a rise in temperature from about 1400 hours onwards, due to the model predicting the drying out of the road (Figure 6.17). In fact there was some precipitation just before midnight but this is not included in the model, due to problems of modelling more than one precipitation episode. The model is currently being adjusted to allow the road to be wet at specific periods of the day. Nevertheless the predicted curve does not stray far from the actual road temperature curve.

The predicted temperatures at 18 cm and 36 cm are fine.

17. 25th February - 26th February 1980

The ridge of high pressure to the south west of Britain finally moved in, and with little wind air temperatures dropped quickly to zero before midnight. The humidity was very high and fog restricted the fall in road temperature to a minimum of 2.0°C. The predicted temperature curve is an excellent fit and, due to the low wind speeds, is not pulled down by the cold air temperature (Figure 6.18). The heat exchange with the air is therefore negative throughout the day.

The slab maximum temperature was higher than the road maximum temperature by 1.7°C, yet the slab minimum temperature was cooler by

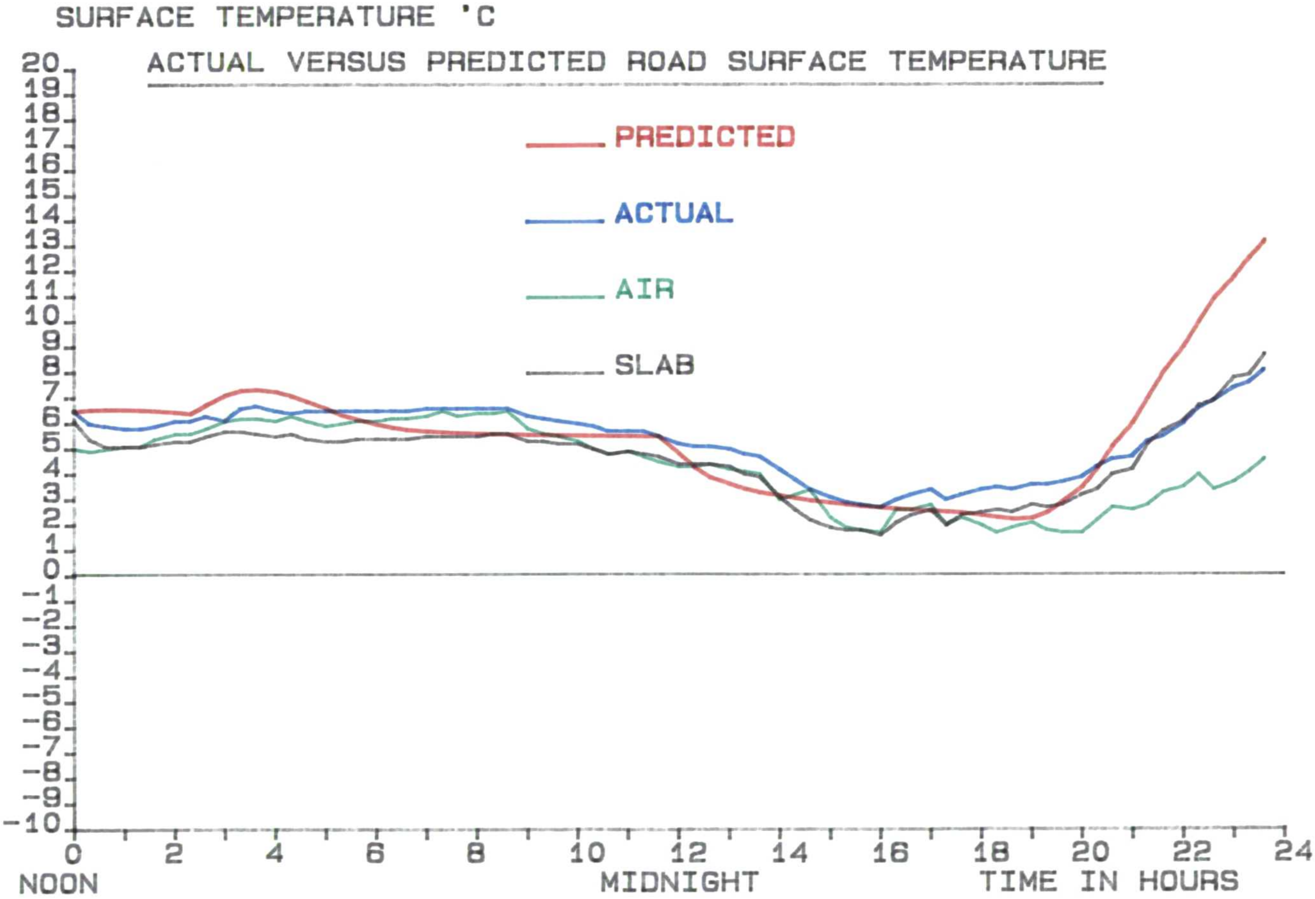
DATE: 24-25 FEBRUARY 1980

FIGURE 6.17

DEC: -9.31 R: .990

BOUNDARY CONDITIONS: UA1, UA2: 418.0 104.0 TIME WET: 12

	1200	1500	1800	2400	0600
T0'C	6.5				
T18'C	5.3				
T36'C	6.2				
TA'C	5.3	6.1	5.7	3.1	2.8
RHF	.93	.95	.95	.97	.96
CLOUD	8		8	5	5
	LOW		LOW	LOW	LOW

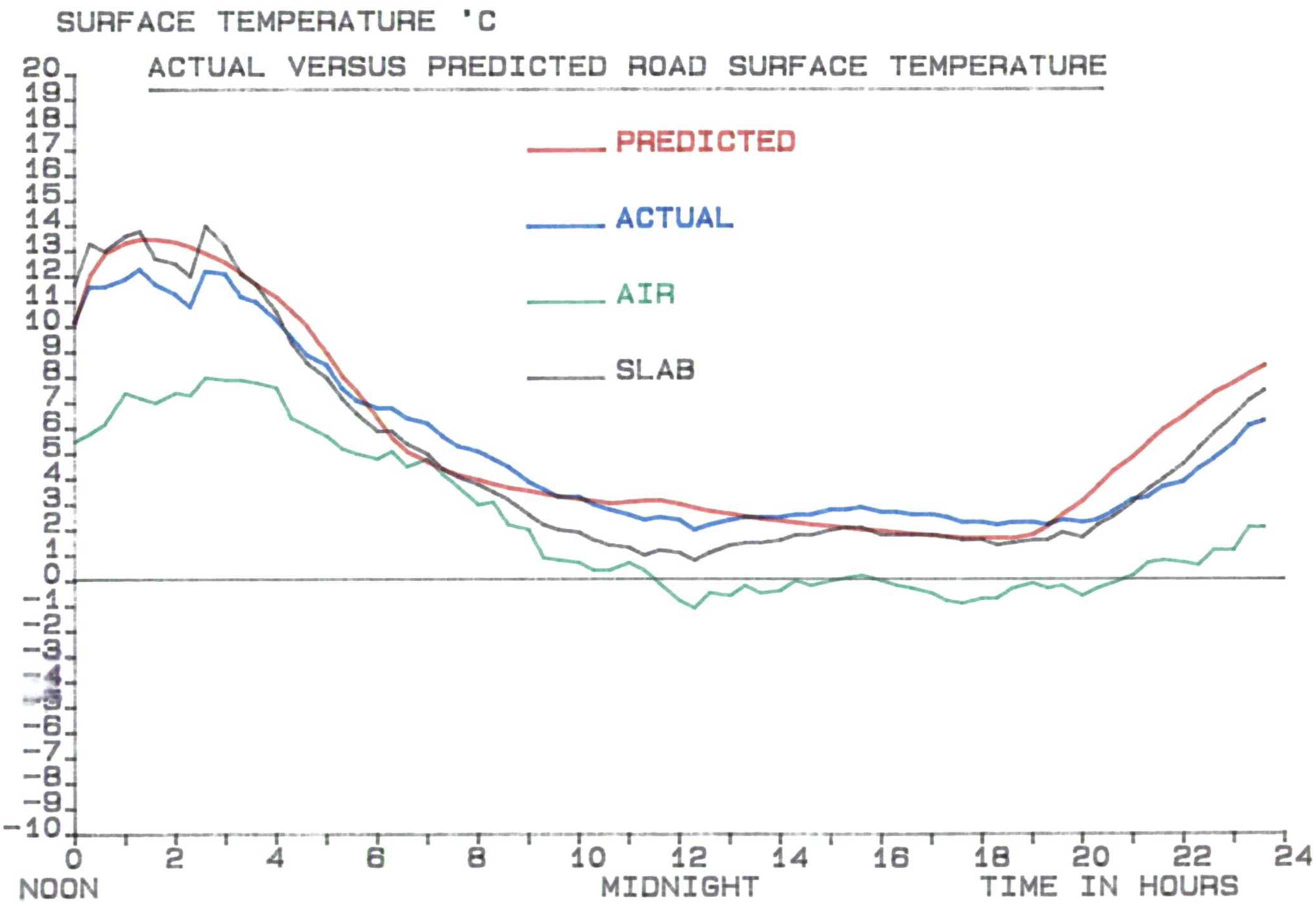


DATE: 25-26 FEBRUARY 1980 FIGURE 6.18

DEC: -8.94 R: .990

BOUNDARY CONDITIONS: UA1, UA2: 107.0 23.0 TIME WET: 17

	1200	1500	1800	2400	0800
TO'C	10.2				
T18'C	6.0				
T36'C	6.1				
TA'C	6.9	6.6	2.3	-.4	.4
RHF	.87	.81	.92	.98	.96
CLOUD	6		6	8	8
	LOW		LOW	LOW	LOW



1.2°C. This adds support to the theory that the motorway diurnal temperature curve is flattened by the effect of traffic. Thus the maximum predicted by the model might be expected to approach the slab maximum more closely than the motorway maximum.

The predicted temperatures at 18 cm and 36 cm are fine.

18. 3rd March - 4th March 1980

An anticyclone was firmly established over the country giving little cloud and wind. The air temperature dropped to -3.3°C but the road temperature only just fell below zero to -0.5°C. The predicted maximum temperature is about 7°C too high which suggests that perhaps there was more than 5/8 medium cloud. The predicted minimum temperature is much too low at -2.8°C and this is the biggest residual of the 30 nights considered (Figure 6.19). If the model is run again taking 1/8 low cloud between midnight and 0600 hours instead of 1/8 high, then the predicted minimum is raised to -2.5°C, which perhaps suggests that due to local topography a value of less than 1/8 low cloud is unrealistic. The only cloud recorded at Beaufort Park and Benson after 1800 hours was cirrus, but it was obviously sufficient to prevent considerable road cooling. The cloud factors in the model perhaps need to be re-examined for high cloud, although traffic of course is a complicating factor that makes it difficult to speculate the full cooling under high cloud conditions.

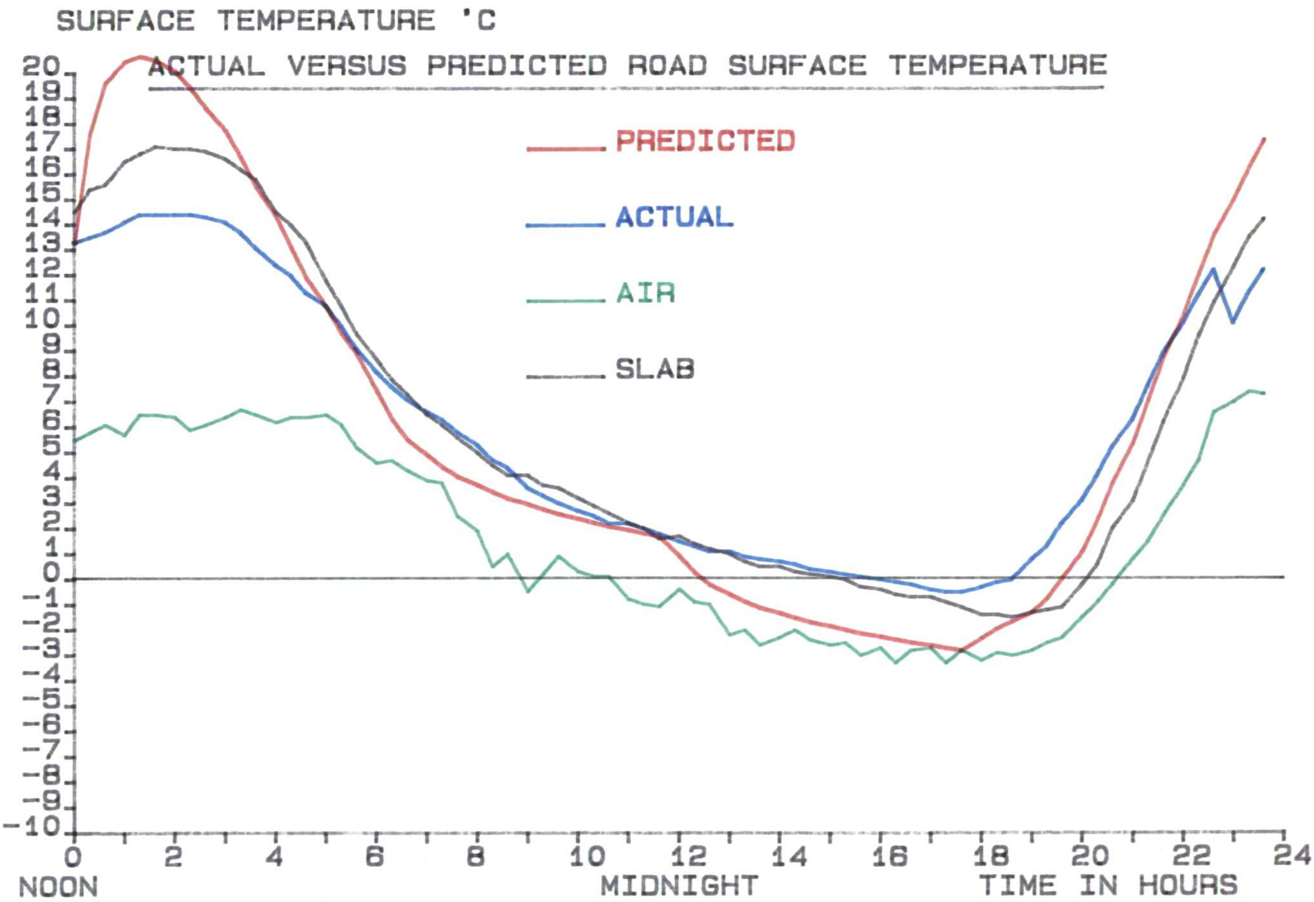
The amplitudes of the predicted 18 cm and 36 cm curves are greater than the actual curves due to the large predicted amplitudes of the road surface temperature. However the curves do not significantly differ.

DATE: 03-04 MARCH 1980 FIGURE 6.19

DEC: -6.28 R: .992

BOUNDARY CONDITIONS: UA1, UA2: 139.0 78.0 TIME WET: 0

	1200	1500	1800	2400	0600
TO'C	13.3				
T18'C	7.8				
T36'C	7.4				
TA'C	6.1	6.3	1.4	-2.3	1.2
RHF	.54	.54	.89	.86	.82
CLOUD	5		5	1	3
	MED		HIH	HIH	HIH



The terms in the heat balance equation are much bigger at this time of year. Values of Richardsons Number exceeding ±0.01 are observed during the day, which strictly speaking means that a neutral profile did not exist above the road. However the values are still small and at this time of year there is little chance of the motorway causing convection.

19. 4th March - 5th March 1980

The anticyclone moved eastwards and a belt of cloud associated with a frontal system moved in from the west. The cloud did not reach south east England until just before dawn however, by which time the minimum air temperature had dropped to -2.2°C. The road temperature stayed just above zero with a minimum of +0.4°C (Figure 6.20). The model predicts a minimum of -1.2°C which represents the second prediction of the 30 nights considered when the actual and predicted road temperature are on either side of 0°C. The slab minimum temperature was -0.5°C but the effect of traffic alone cannot be expected to explain such a relatively warm minimum road temperature. A sensitivity analysis reveals that the model predicts a minimum below zero even if the cloud is considered to be all low cloud throughout the night (4/8M, 4/8L, 4/8L, 7/8L gives a predicted minimum of -0.9°C). The cloud had cleared completely at both Beaufort Park and Benson by 0300 hours. It is inevitable that with a mean absolute error of 0.65°C the prediction will be on the wrong side of 0°C on some occasions! The predicted temperatures at 18 cm and 36 cm are both generally too cold due to the predicted surface curve being too cold for most of the day. The evidence suggests that the night time cloud inputs to the model are probably better set at low cloud rather than at medium or high due to the effect of topography and traffic.

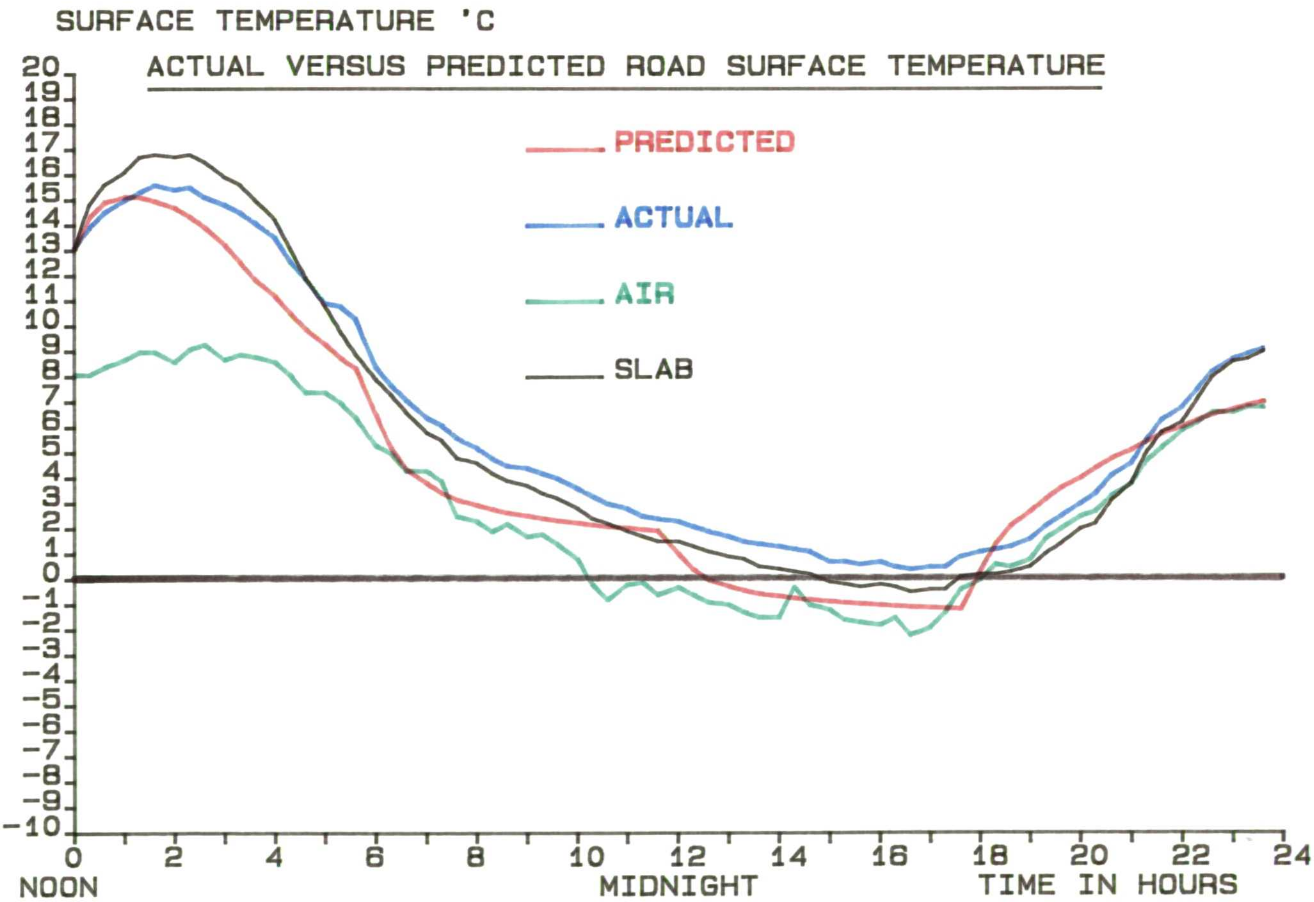
DATE: 04-05 MARCH 1980

FIGURE 6.20

DEC: -5.89 R: .992

BOUNDARY CONDITIONS: UA1, UA2: 426.0 575.0 TIME WET: 0

	1200	1500	1800	2400	0600
TO'C	13.1				
T18'C	6.2				
T36'C	6.0				
TA'C	8.7	7.9	2.0	-1.2	3.7
RHF	.61	.60	.75	.85	.81
CLOUD	4		4	3	7
	LOW		MED	MED	LOW



20. 6th March - 7th March 1980

A wet day with first an occluded front and then a cold front moving from west to east across the country. The passage of both fronts is clearly shown by the air temperature trace in Figure 6.21, the air temperature rising to about 11°C in the early evening and falling sharply by about 2°C just after midnight. Because of the precipitation and high winds the road temperature followed the air temperature clearly, and the predicted road temperature curve is quite good. The model predicts that the road would have dried out by about 0300 hours which, of course, is unlikely due to the passage of the cold front. If the model had kept the road wet, no doubt the predicted minimum could have been closer to the actual minimum. The predicted temperatures at 18 cm and 36 cm are fine until the road is predicted to dry out.

21. 7th March - 8th March 1980

Another wet day with a complex area of low pressure over south east England moving across to the continent. As for the previous day the predicted road temperature is fine (Figure 6.22). The model predicts that the road dries out very quickly - by about 1600 hours, due to the high wind. This quick drying is confirmed by the slab wetness meter which appeared to dry out by about 0200 hours, the increase in temperatures from that time onwards was probably due to an increase in cloud associated with the next frontal system moving in from the west. The predicted temperatures at 18 cm and 36 cm are fine.

22. 8th March - 9th March 1980

The frontal system that crossed the country during the day did not bring with it any rain. The maximum road temperature at about 14°C was

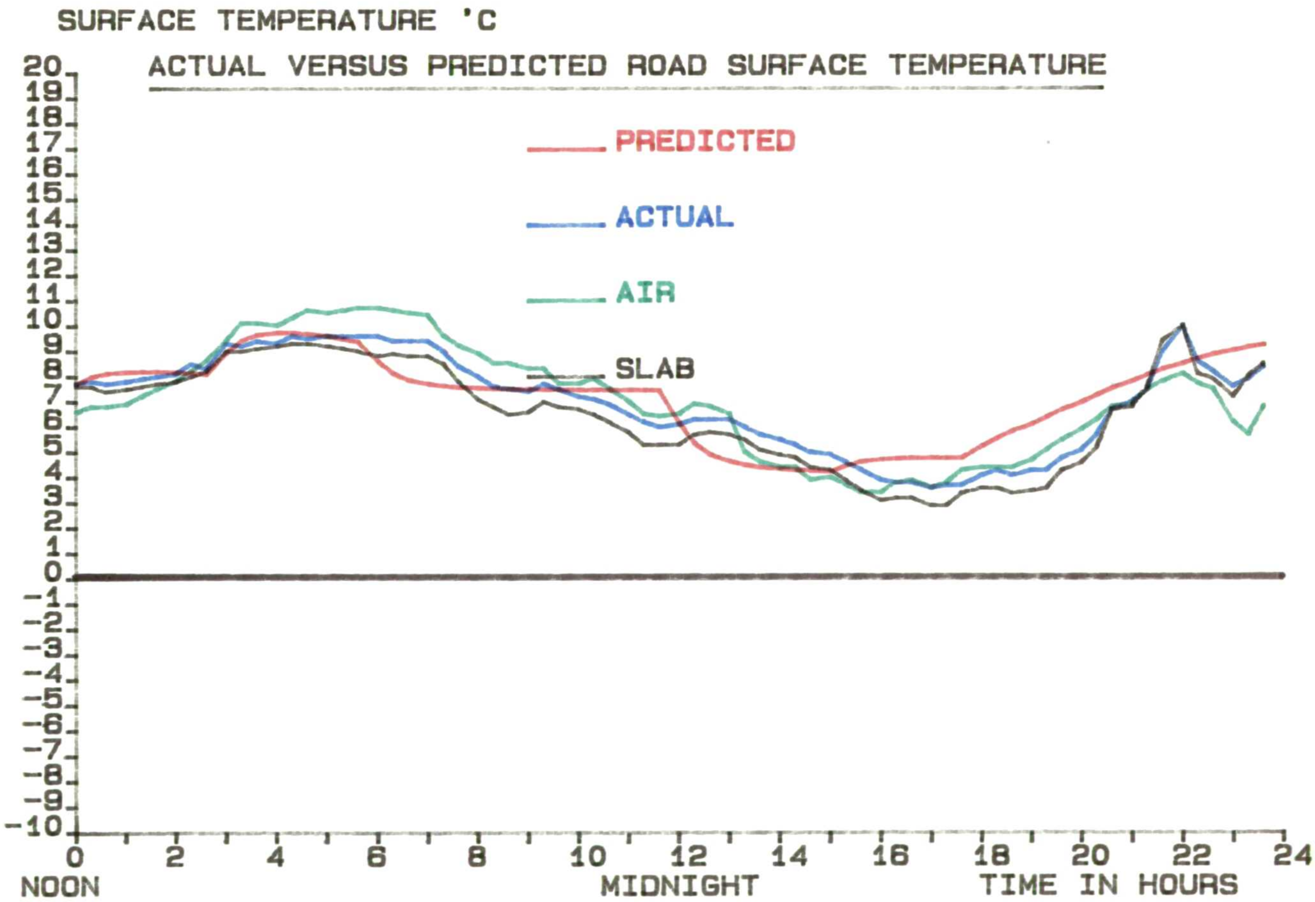
DATE: 06-07 MARCH 1980

FIGURE 6.21

DEC: -5.12 R: .993

BOUNDARY CONDITIONS: UA1, UA2: 661.0 731.0 TIME WET: 12

	1200	1500	1800	2400	0600
TO'C	7.7				
T18'C	6.8				
T36'C	6.6				
TA'C	7.4	10.3	8.6	4.6	6.2
RHF	.94	.90	.86	.90	.87
CLOUD	8		7	7	6
	LOW		LOW	LOW	LOW



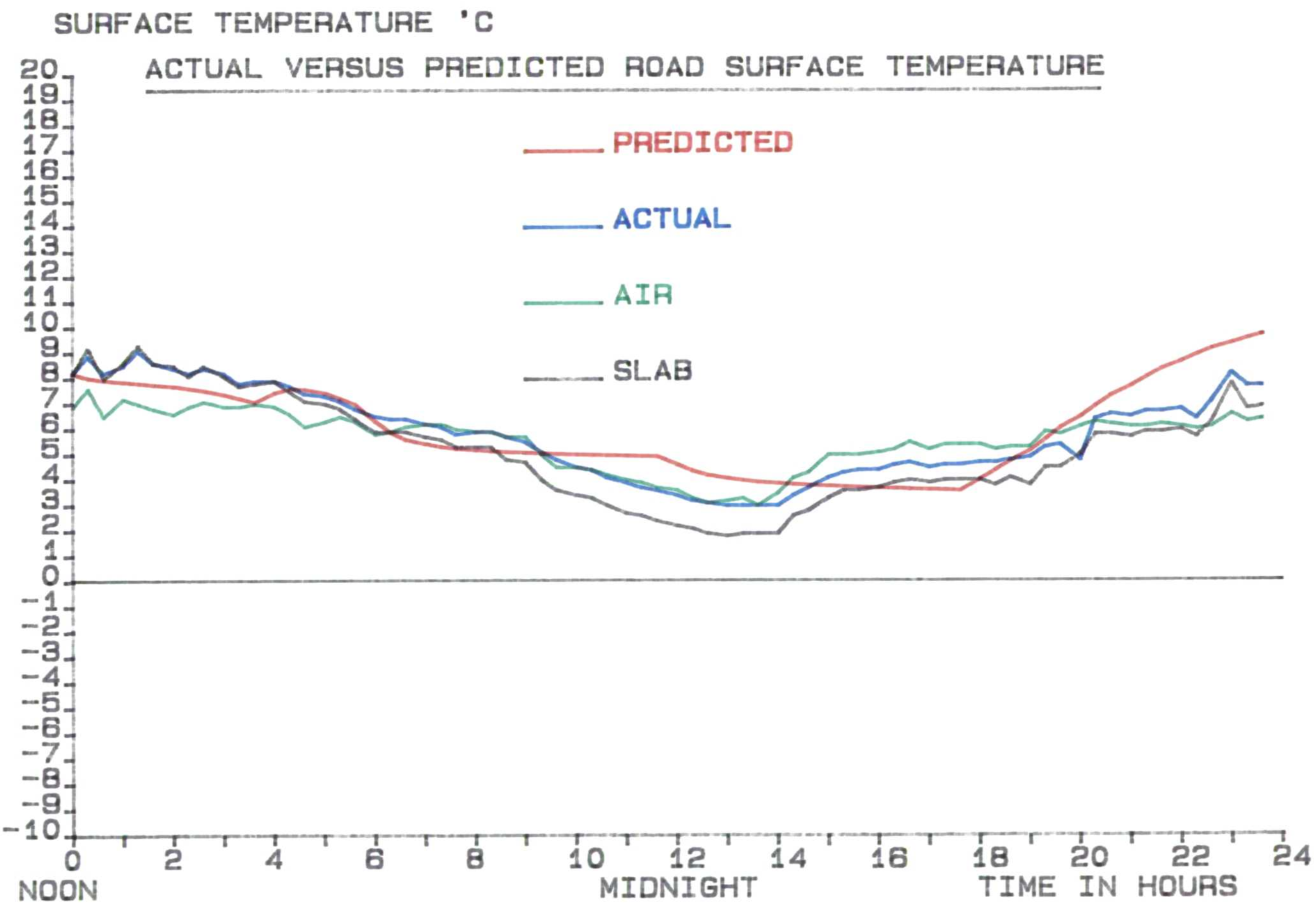
DATE: 07-08 MARCH 1980

FIGURE 6.22

DEC: -4.73 R: .993

BOUNDARY CONDITIONS: UA1, UA2: 647.0 241.0 TIME WET: 12

	1200	1500	1800	2400	0600
TO'C	8.2				
T18'C	7.0				
T36'C	6.7				
TA'C	7.0	6.6	5.2	4.3	6.0
RHF	.85	.88	.87	.93	.89
CLOUD	7		5	5	8
	LOW		LOW	LOW	LOW



about 5°C greater than the maximum air temperature (Figure 6.23). The model predicted road surface temperature curve is very good apart from the predicted maximum. The 6/8 stratocumulus that covered the site for much of the night and morning is clearly shown as broken cloud in the satellite photo for 1443 hours on the 9th March.

23. 9th March - 10th March 1980

The broken stratocumulus and cumulus continued through the afternoon and evening before an occluded front moved through from the west in the early hours of the morning. The air temperature picked up quickly from around 0200 hours. The predicted road minimum is lower that the actual road minimum as the average cloud for the period midnight to 0600 hours was 6/8 low whereas the sky was overcast for much of the period. The predicted curve is remarkable for the surface (Figure 6.24) and for 18 cm and 36 cm is good.

24. 10th March - 11th March 1980

The occluded front quickly moved east to be followed by clearer skies and then an approaching warm front. The road remained dry however, and the predicted road temperature curve is very good, the predicted minimum being within 0.1°C of the actual minimum (Figure 6.25). Consequently the predicted 18 cm and 36 cm temperatures are fine, and the heat balance is uncomplicated.

25. 20th March - 21st March 1980

A strong, cold, easterly air stream with little cloud gave a difference of more than 9°C between the maximum air and road temperature (Figure 6.26). The predicted road temperature curve does not give as high a

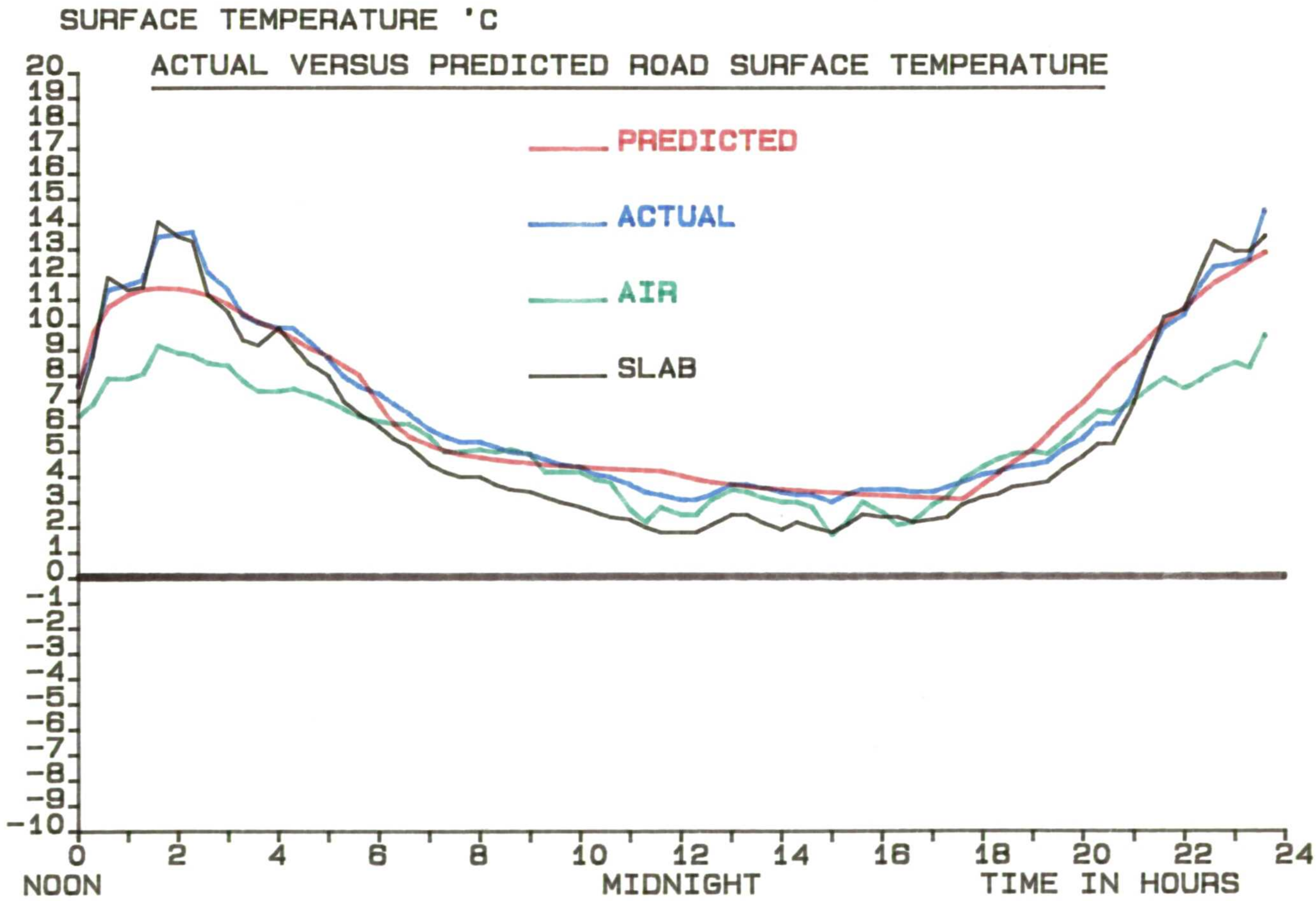
DATE: 08-09 MARCH 1980

FIGURE 6.23

DEC: -4.34 R: .993

BOUNDARY CONDITIONS: UA1, UA2: 499.0 131.0 TIME WET: 0

	1200	1500	1800	2400	0600
TO'C	7.6				
T18'C	6.5				
T36'C	6.4				
TA'C	8.1	7.3	4.6	2.8	6.7
RHF	.72	.73	.91	.95	.88
CLOUD	6		3	6	6
	LOW		MED	LOW	LOW



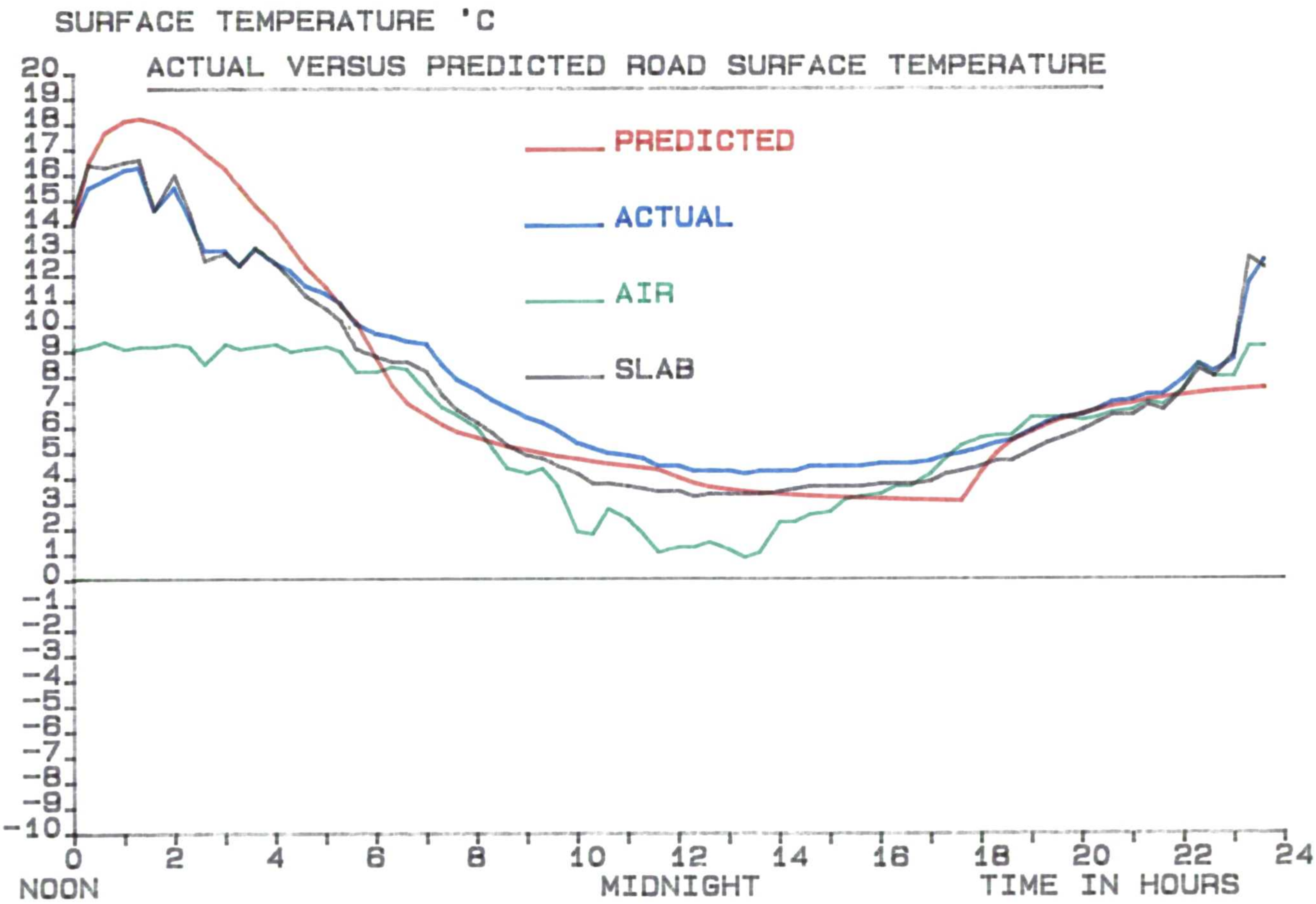
DATE: 09-10 MARCH 1980

FIGURE 6.24

DEC: -3.95 R: .993

BOUNDARY CONDITIONS: UA1, UA2: 266.0 629.0 TIME WET: 6

	1200	1500	1800	2400	0600
T0'C	14.1				
T18'C	7.8				
T36'C	6.3				
TA'C	9.1	9.0	4.7	2.7	7.0
RHF	.60	.56	.78	.84	.89
CLOUD	5		3	6	8
	LOW		MED	LOW	LOW

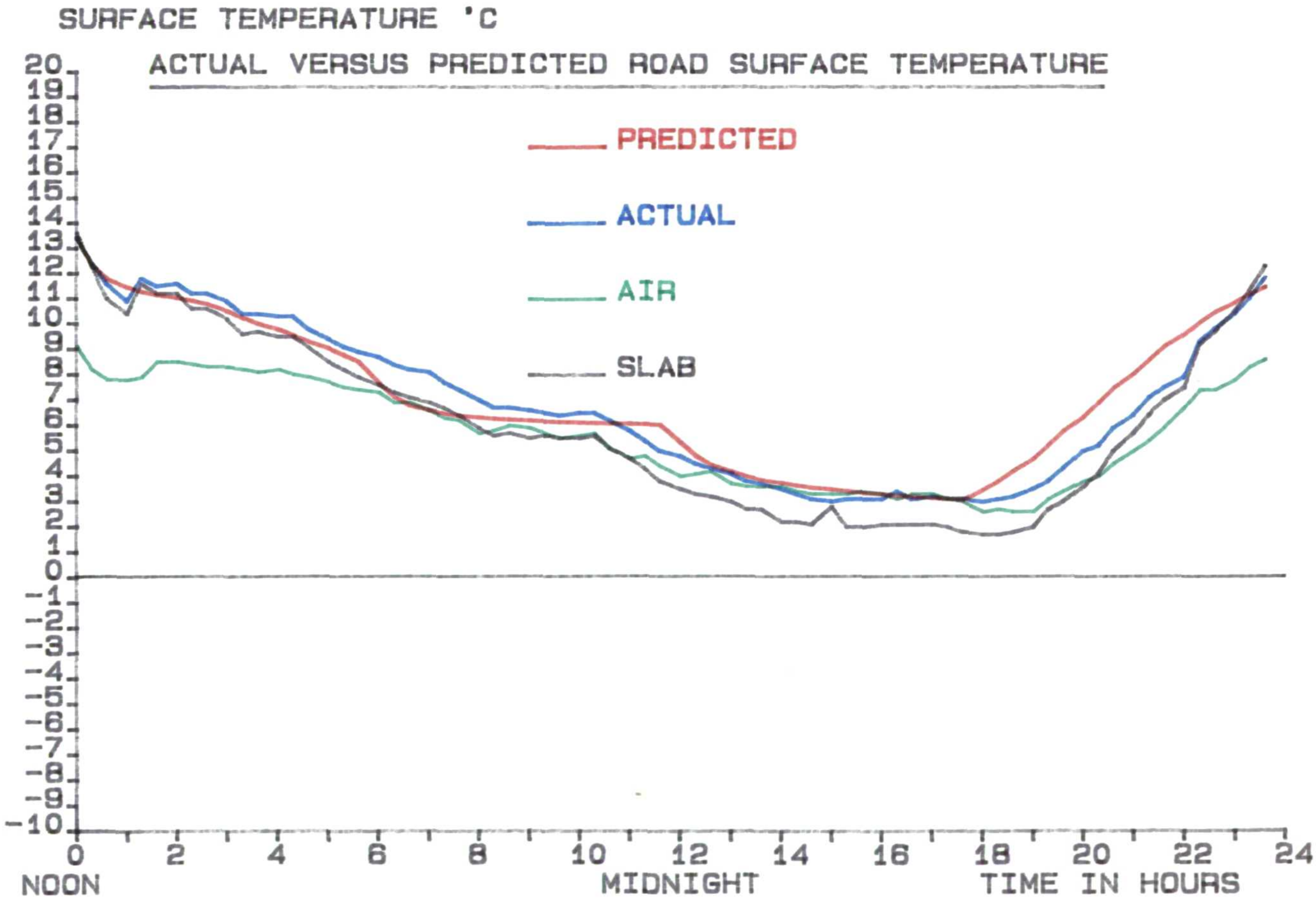


DATE: 10-11 MARCH 1980 FIGURE 6.25

DEC: -3.55 R: .994

BOUNDARY CONDITIONS: UA1, UA2: 865.0 174.0 TIME WET: 0

	1200	1500	1800	2400	0600
TO'C	13.4				
T18'C	7.8				
T36'C	7.0				
TA'C	8.3	7.9	5.8	3.5	5.1
RHF	.71	.69	.76	.84	.83
CLOUD	7		7	5	7
	LOW		LOW	LOW	LOW

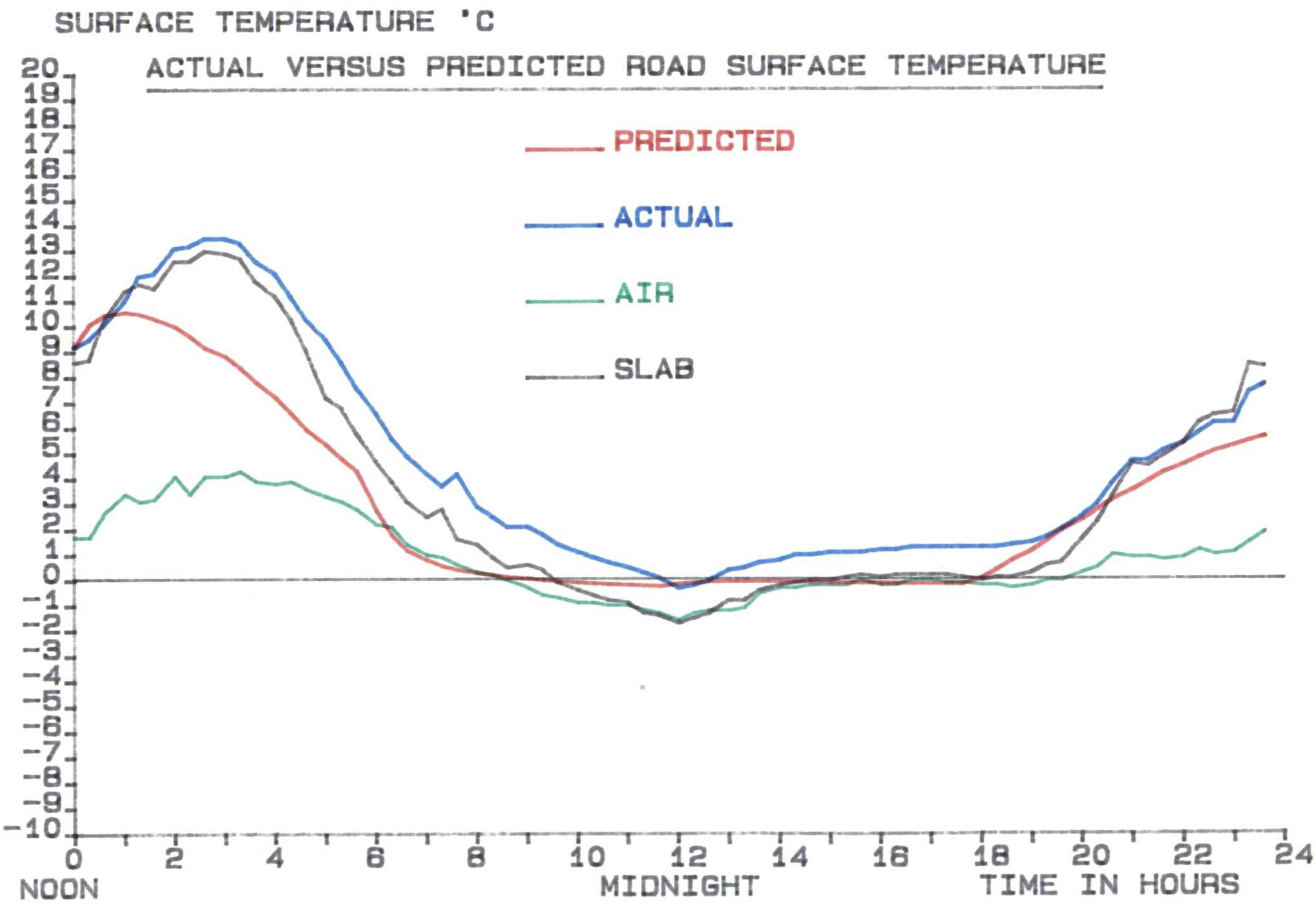


DATE: 20-21 MARCH 1980 FIGURE 6.26

DEC: .40 R: .996

BOUNDARY CONDITIONS: UA1, UA2: 907.0 417.0 TIME WET: 0

	1200	1500	1800	2400	0600
TO'C	9.2				
T18'C	5.2				
T36'C	4.6				
TA'C	3.0	3.6	.0	-.5	.6
RHF	.58	.52	.56	.82	.76
CLOUD	2		1	7	7
	LOW		LOW	LOW	LOW



maximum as the actual road despite the relatively large influx of solar radiation at this time of year. The reason is due to the relatively large predicted heat exchange with the cold air. Such a large temperature gradient between the road and air is a product of the wind direction. The M4 at the site runs from roughly ESE to WNW so that a strong easterly wind means that the air temperature instrument measures the air temperature before the air has passed over the warm road. During the months of December, January and February when the road maximum temperature rarely reaches 10.0°C the effect of wind direction on the difference between road and air temperature is not likely to be large. During the rest of the year when the road maximum is much higher than the air maximum due to the direct absorption of solar radiation by the surface, then wind direction is likely to be more important. This was discussed in more detail in Chapter 4.

The actual road temperature fell to 0°C just before midnight and then rose as cloud increased due to an approaching cold front. The predicted curve falls → 0°C at about 2100 hours and stays just below until 0600 hours. The predicted minimum is excellent, but the duration below 0°C is poor. As the road was dry this would not have presented any problems. In reality the movement of the cold front was unpredictable and the Meterological Office forecast a minimum road surface temperature of -6.0°C!

The predicted 18 cm temperature is rather too cold at first but is reasonable during the night. The predicted 36 cm temperature is quite good.

26. 21st March - 22nd March 1980

A weak dry cold front crossed the region during the day and the sky cleared quickly shortly after midnight to give a road surface minimum of -2.8°C at 0600 hours. The model predicts a minimum of -4.4°C and this night is the subject of the sensitivity analysis in the last Chapter. The predicted curve is good in terms of the time of falling below 0°C, but, as can be seen from Figure 6.27, it falls too low after midnight. Perhaps more than 1/8 low cloud was present after midnight. The predicted 18 cm and 36 cm curves are fine and the heat balance suggests that a small amount of hoar frost might have been deposited. Because the road was dry there was no danger of ice formation.

27. 22nd March - 23rd March 1980

The air temperature remained cold for much of the day but began to increase after midnight as the cloud associated with a depression moved in from the west. The predicted curve is very good for both the maximum and minimum road temperature (Figure 6.28). The heat balance was straight forward, and the 18 cm and 36 cm predicted temperatures are fine.

28. 1st April - 2nd April 1980

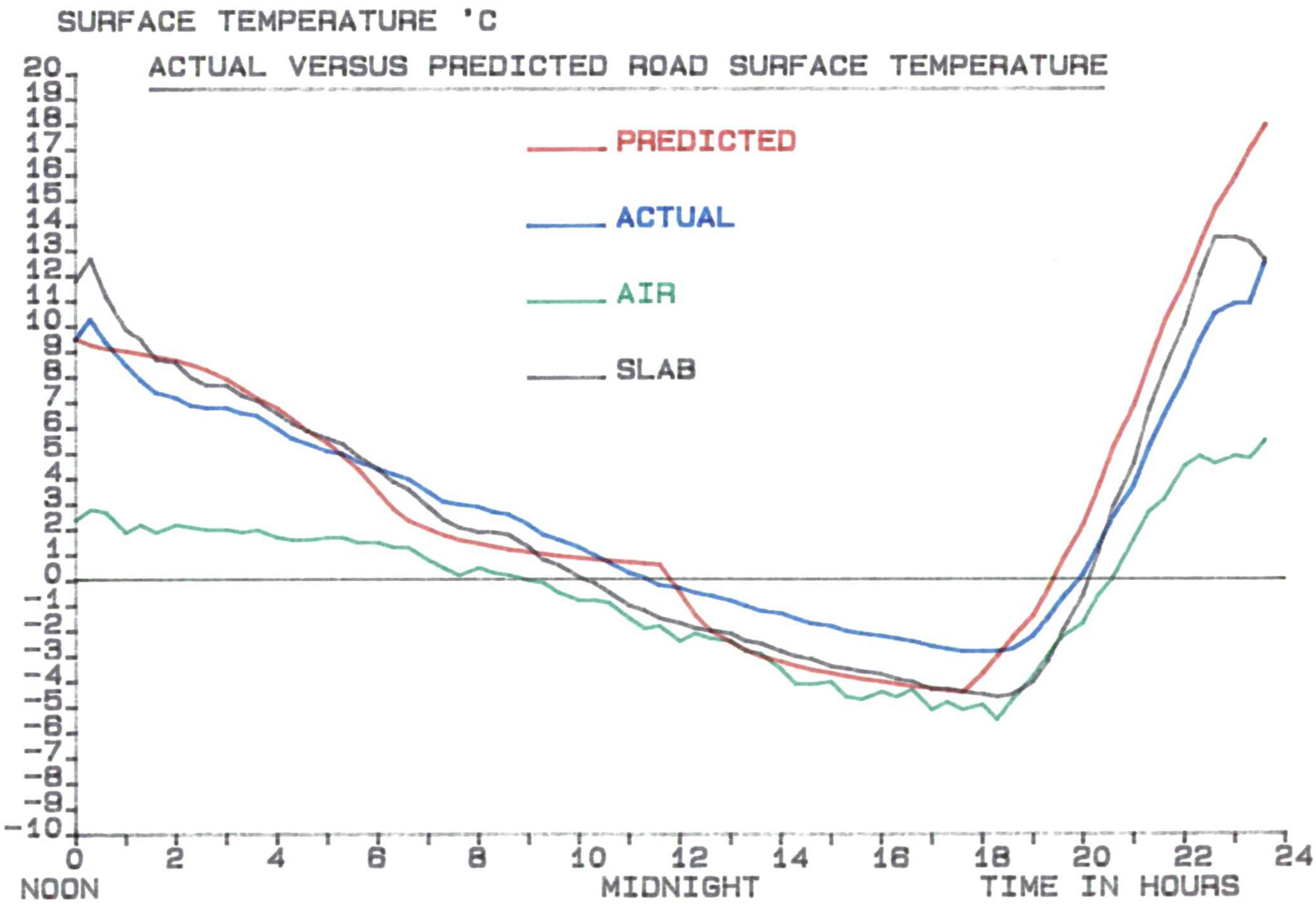
The cloud associated with a deep depression to the north of Scotland brought some quite heavy rain, but by late evening, the sky cleared and an anticyclone established its influence over most of Britain. Because of strong winds the model predicts that the road would have quickly dried out, before 1900 hours, which is a little premature in view of the fact that the rain at Benson didn't stop until about that time. Nevertheless the slab did appear to dry out by about that time, and the predicted

DATE: 21-22 MARCH 1980 FIGURE 6.27

DEC: .79 R: .997

BOUNDARY CONDITIONS: UA1, UA2: 280.0 136.0 TIME WET: 0

	1200	1500	1800	2400	0600
TO'C	9.5				
T18'C	4.8				
T36'C	4.7				
TA'C	2.2	1.7	-.1	-3.8	.6
RHF	.76	.65	.71	.79	.79
CLOUD	7		6	1	2
	LOW		LOW	LOW	LOW

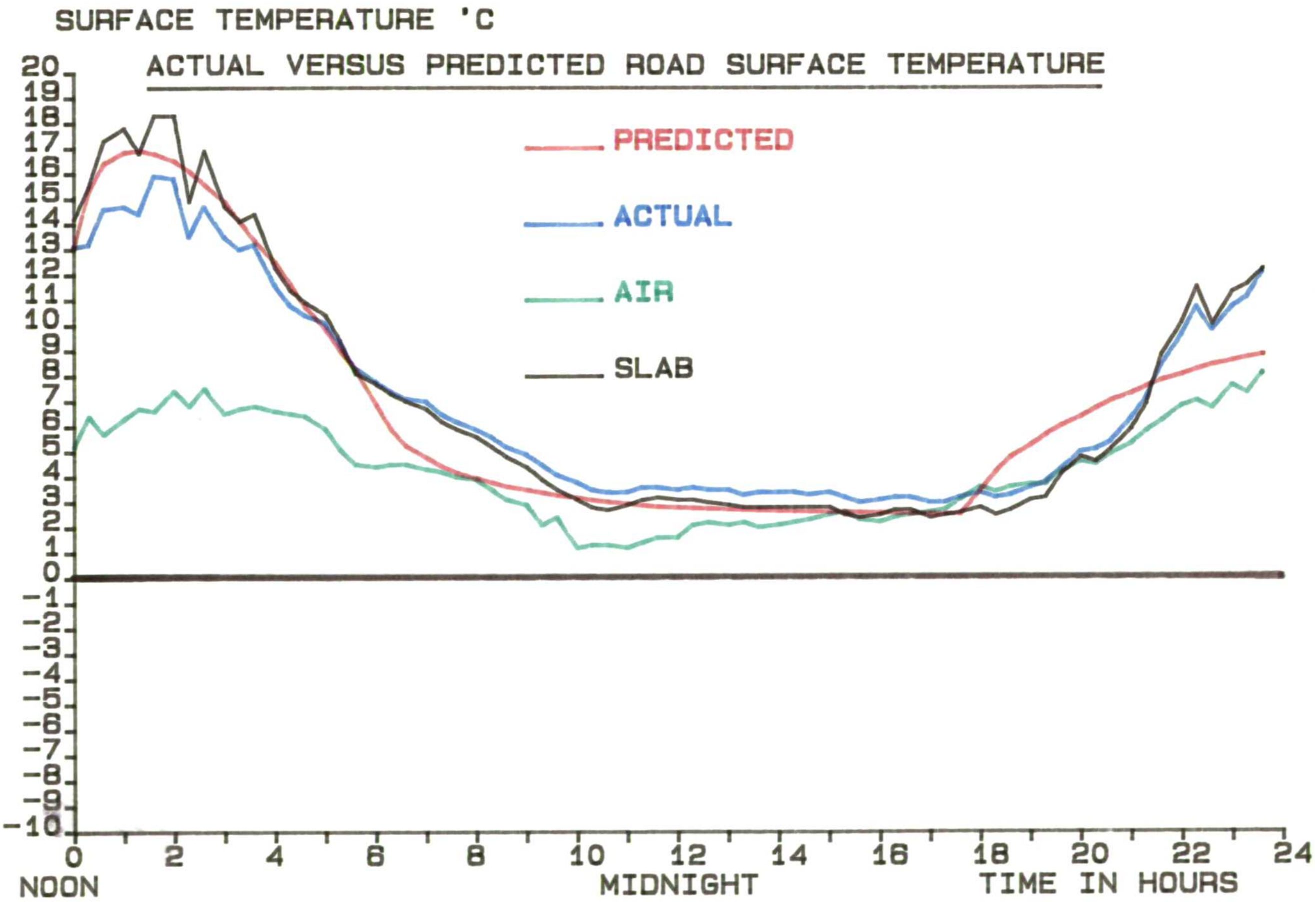


DATE: 22-23 MARCH 1980 FIGURE 6.28

DEC: 1.18 R: .997

BOUNDARY CONDITIONS: UA1, UA2: 297.0 719.0 TIME WET: 0

	1200	1500	1800	2400	0600
TO'C	13.1				
T18'C	5.0				
T36'C	3.8				
TA'C	6.5	6.1	2.9	2.3	5.4
RHF	.51	.49	.76	.70	.73
CLOUD	4		4	7	7
	LOW		LOW	LOW	LOW



temperature curve is quite good (Figure 6.29). The air temperature remained quite warm in the night and therefore despite the clearing cloud the road temperature stayed well above 0°C. The predicted temperatures at 18 cm and 36 cm are fine.

29. 2nd April - 3rd April 1980

A fairly bright day under the influence of the anticyclone with reports of cumulonimbus at Benson during the afternoon. The predicted curve is very good for both the maximum and minimum road temperature (Figure 6.30). The road was dry so that the heat balance is straight forward, and the predictions for 18 cm and 36 cm are fine.

30. 3rd April - 4th April 1980

The anticyclone persisted to give a road maximum temperature of plus 20°C. The predicted curve is too low during the night however probably due to the cold air temperature and the lack of cloud (Figure 6.31). The heat balance and temperatures at 18 cm and 36 cm are fine.

6.3 Overall Performance of the Model

Retrospectively, the model provides a very good guide to the observed diurnal curve of road surface temperature. Nevertheless there are still many features of the model that require further investigation and possible improvement.

6.3.1 Use of Average Input Values

The use of average air temperature, windspeeds and cloud amount mean that the diurnal curve is stepped, at 1500, 1800, 2400 and 0600 hours as the input values change. The most notable effect is at 0600

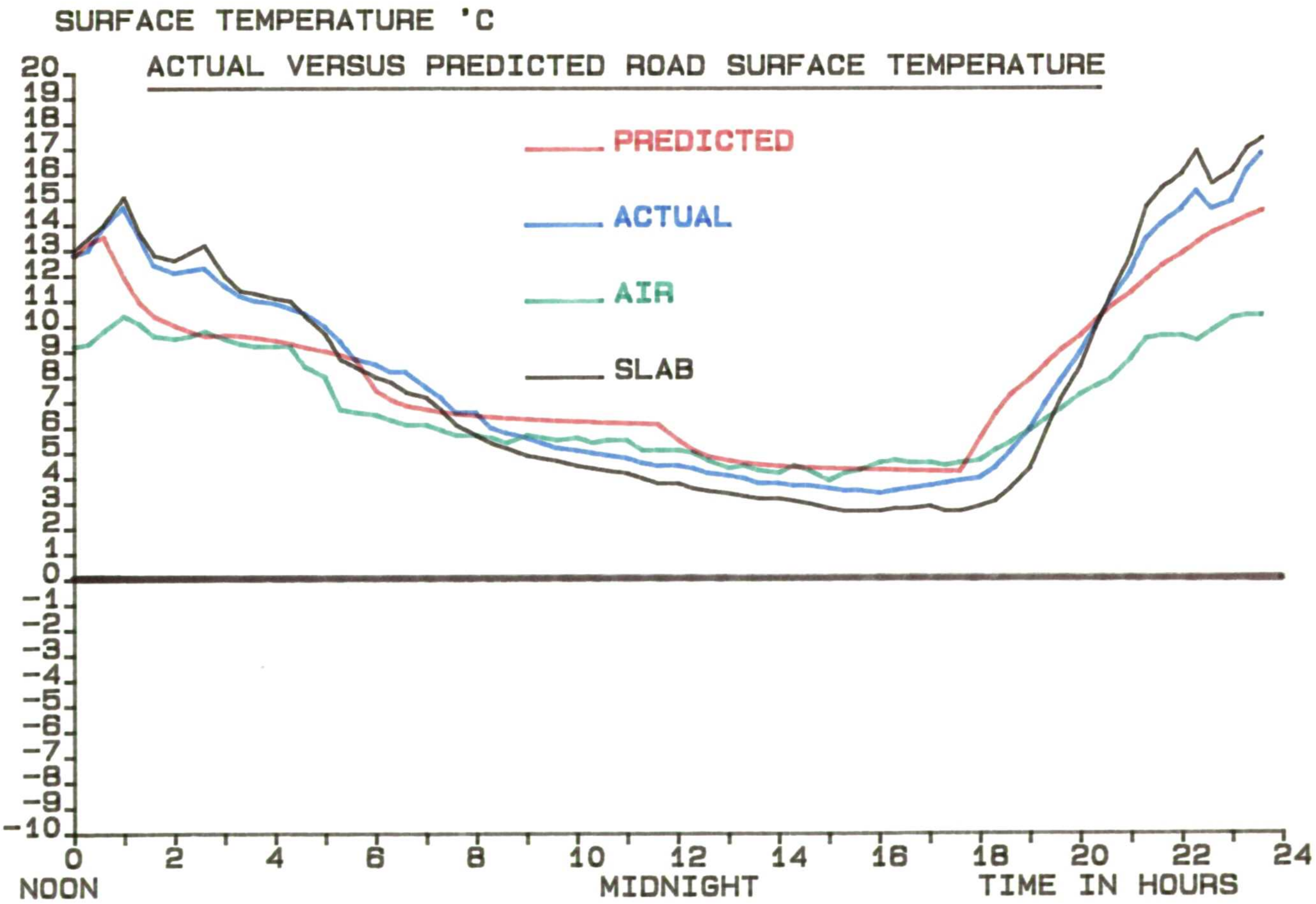
DATE: 01-02 APRIL 1980

FIGURE 6.29

DEC: 5.08 R: 1.000

BOUNDARY CONDITIONS: UA1, UA2: 765.0 827.0 TIME WET: 13

	1200	1500	1800	2400	0600
TO'C	12.8				
T18'C	12.3				
T36'C	9.5				
TA'C	9.7	8.5	5.7	4.5	8.0
RHF	.72	.92	.90	.88	.77
CLOUD	7		6	1	3
	LOW		LOW	LOW	LOW



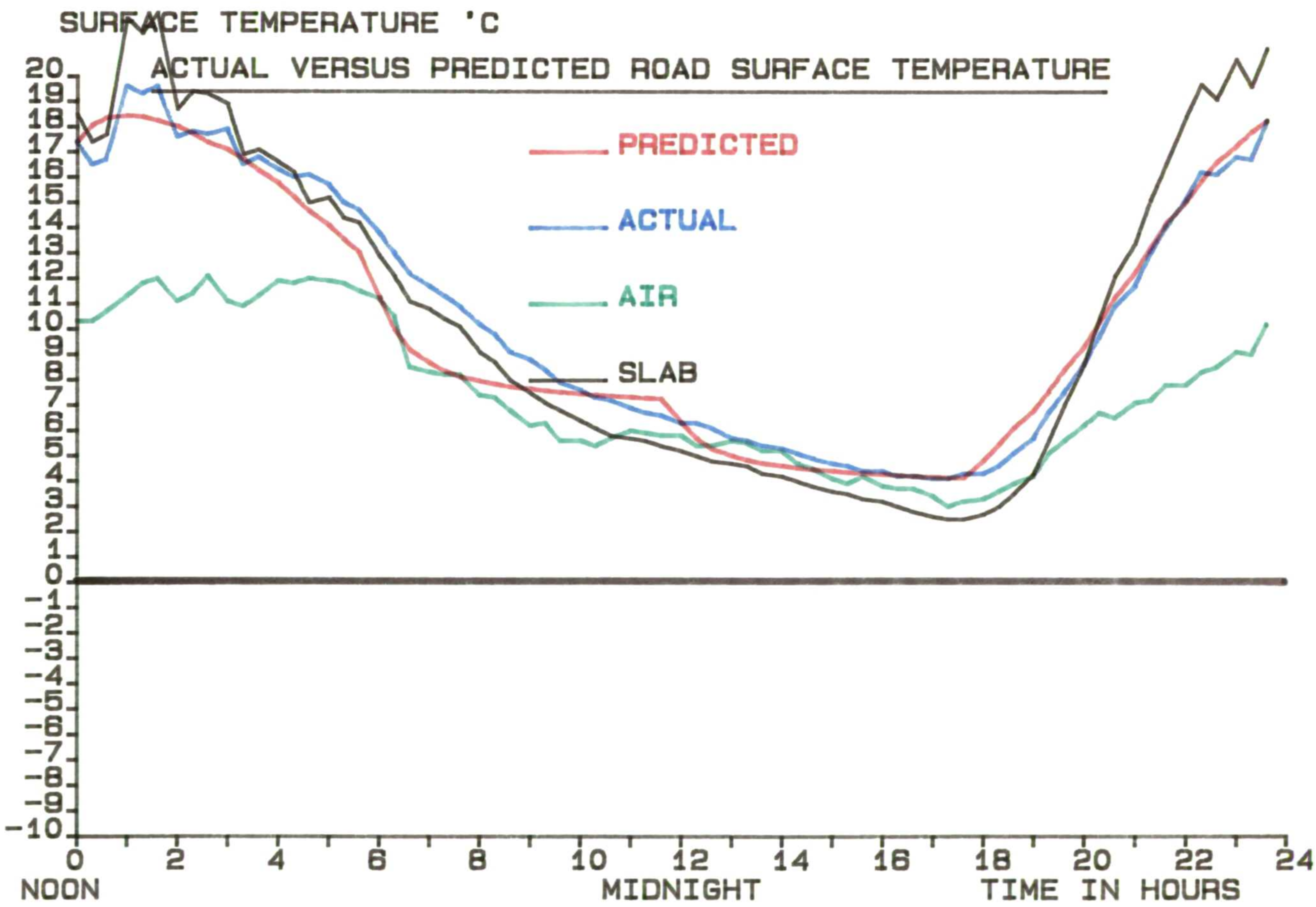
DATE: 02-03 APRIL 1980

FIGURE 6.30

DEC: 5.47 R: 1.000

BOUNDARY CONDITIONS: UA1, UA2: 705.0 501.0 TIME WET: 0

	1200	1500	1800	2400	0600
TO'C	17.4				
T18'C	10.0				
T36'C	8.1				
TA'C	11.2	11.6	7.2	4.5	6.7
RHF	.60	.53	.74	.91	.84
CLOUD	5		4	1	2
	LOW		LOW	LOW	LOW



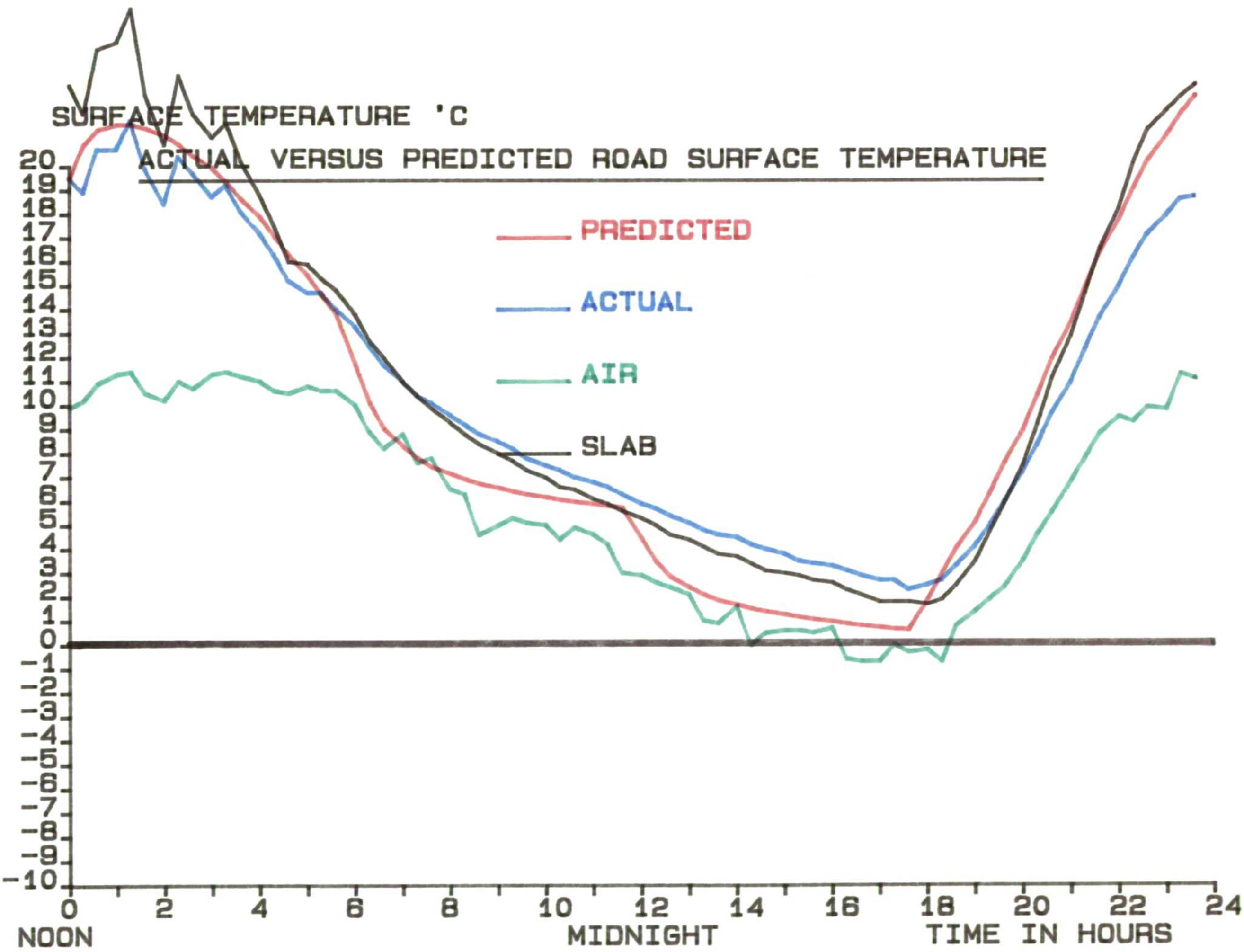
DATE: 03-04 APRIL 1980

FIGURE 6.31

DEC: 5.85 R: 1.000

BOUNDARY CONDITIONS: UA1, UA2: 355.0 281.0 TIME WET: 0

	1200	1500	1800	2400	0600
TO'C	19.5				
T18'C	10.8				
T36'C	8.7				
TA'C	10.7	10.9	6.1	.8	5.8
RHF	.80	.52	.73	.90	.83
CLOUD	5		1	1	2
	LOW		MED	HIH	HIH



hours when the average air temperature for the period 0600-1200 hours is introduced. This average temperature is almost always warmer than the air temperature for the period 2400-0600 hours and hence the predicted minimum road temperature is almost always at 0540 hours. It might be better to take averages over different six hour periods in an attempt to straddle the period around dawn which is normally the coldest time. However, Table 6.1 shows that the actual minimum road surface temperature was rarely at or near dawn. On only 2 nights out of 30 was the actual minimum after 0540 hours. This is due to our ever changing weather and to the lack of clear nights in the observation period, and also, perhaps, to the increase in traffic well before dawn in winter. The likely effect of traffic on road surface temperatures has not, of course, been built into the model. For real time forecasting this problem has been overcome by linearly extrapolating the air temperatures between forecast values. This is fine, unless the minimum air temperature is at a significantly different time from the forecast time.

6.3.2 The Likely Effect of Traffic on Road Surface Temperatures

Very little research has been done on the effect of traffic on road temperatures. Sorbjan (1976) has theoretically estimated that the contribution of traffic to the eddy transfer in the boundary layer is proportional to the traffic density, multiplied by the mean vehicle speed cubed. He has not presented any empirical evidence however, to compare this with actual observations. Traffic will effect parameters other than the tubulent heat exchange with the air. Table 6.2 lists the likely influences of traffic on road temperatues in winter. The list is speculative and, generally speaking, the influence of the traffic will depend upon the temperature gradient between the air

Table 6.2 The Likely Effects of Traffic on the Components of the Heat Balance Equation in Winter

				Effect on T_{Max}	Effect on T_{Min}
A.	RN	(i)	Prevents solar radiation reaching surface	Decrease	Very Little
		(ii)	Prevents terrestrial radiation escaping from surface	Increase	Increase
		(iii)	Gain of longwave from hot parts of vehicle	Increase	Increase
B.	H	(i)	Increased mixing	Decrease	Depends on ΔT_{A-R}
		(ii)	Air warmed by engines and exhaust	Increase	Increase
		(iii)	Roughness length increased	Decrease	Depends on ΔT_{A-R}
C.	S	(i)	Conduction from warm tyres	Increase	Increase
D.	LE	(i)	Increased splash and turbulence will dry out road	Increase	Increase

and the road, and the existing wind field. As far as the maximum road temperature is concerned referring to Table 6.2 it is likely that effects A(i), B(ii) and B(iii) that tend to decrease the maximum are probably greater in influence than the other effects put together, such that the maximum is lowered. During the day time normally the road is warmer than the air and increased mixing will reduce that temperature difference. The minimum road temperature will be increased most of all by A(ii), but most of the factors tend to offset cooling. Increased mixing by traffic may help to offset cooling by preventing the formation of ground inversions over the road, and mixing down warmer air.

Traffic density usually varies more than traffic speed, and hence the influence of the traffic will be most dependent on traffic density. The density varies diurnally but for the M4 traffic is considerable for most of the 24 hour period. Further research is required to see if there is a quantifiable relationship between road temperature and traffic density. Research outlined in the next chapter using infra-red thermal mapping of road surface temperatures has revealed differences of up to 2°C between the slow and fast lanes of motorways - presumably due to differences in traffic density.

6.3.3 The Effect of Precipitation

The model used for this chapter is designed to give three choices of input for precipitation, but only one time of commencement is possible. Hence, if for instance two fronts with associated rainfall pass over the site, it is not possible to include them both. Nor is it possible to state that the road will remain wet all day regardless of air temperature or wind, which of course it might if the precipitation continues. This has been modified for real time forecasting.

The temperature of the precipitation can also have an effect on the road surface temperature. This is most notable in summer when temperature falls of more than 20°C on the commencement of precipitation are not uncommon. In winter however the temperature differences between the surface and the air are not that great and differences of only one or two degree centigrade are found. Sugrue (1980) has examined this problem in more detail.

6.3.4 Latent Heat Release with the Formation of Ice

Unfortunately, of the 30 nights considered there was not one occasion when the road was wet and the road temperature fell below 0°C. Hence the empirical nature of the calculation of the latent heat release due to the freezing of surface water has not been tested, and is no longer used. Any heat given out by the freezing of surface water would of course be balanced by heat taken in when the surface ice melts.

As far as winter maintenance is concerned the model has done its job if it predicts that the road surface temperature will fall to 0°C when it is known that the road is wet or likely to be wet. The extent to which the road temperature falls below 0°C, or when the road temperature rises back above 0°C is not so important.

6.3.5 Hoar Frost Formation

A weakness of the model as far as winter maintenance is concerned is that although the model can predict hoar frost formation, it is not likely to predict as much as is actually formed due to the use of average air temperatures and hence an average dew point between midnight and

0600 hours. When the model is used for real time forecasting the humidity is calculated every hour and the dew point is recalculated to overcome this problem. Further investigation is required however to determine how much hoar frost is formed on the road surface with different humidity and air temperature gradients. Also the effect of hoar frost on the skid resistance of road surfaces requires further analysis. Thornes (1973) shows how heavy deposits of hoar frost can be compacted into ice by traffic, but that the formation of hoar frost is impeded by traffic. Thus the timing of the hoar frost formation is important. Hoar frost formed in the early hours of the morning can be compacted by rush-hour traffic into ice, whereas hoar frost might not form at all if the traffic is above a certain density.

6.4 Potential of the Model for Real Time Forecasting

The testing of the model in real time is discussed in the next two chapters. The model has been designed as a practical aid to the weather forecaster who issues Road Danger Warnings. The sensitivity analysis carried out in the last chapter showed that the predicted minimum road surface temperature is very sensitive to errors in the input values, such that the difference between a "pessimistic" and an "optimistic" forecast is as high as 4.8°C for the 21/22 March 1980. The problem for the forecaster who has to predict the correct inputs for the model up to 24 hours ahead are great, and to some extent the problem is catch-22. The air temperature is dependent upon the surface temperature and yet we have to use a forecast air temperature to predict the road temperature. A similar problem was encountered when trying to fix the optimum atmospheric damping depth in that the damping depth varies with wind speed, and hence one does not know the optimum height at which to measure the wind until one has measured it! As far as real time forecasting is concerned one has to make assumptions and monitor the performance of the model with these assumptions in mind. Hence an element of empirical tuning of the model is inevitable, as a complete physical understanding of the heat balance of a road surface is not yet possible. A true test of the model can only be accomplished in real time to see whether or not the model can out-perform the local forecaster who at present issues far too many Road Danger Warnings. The model is currently being tested in real time using data from 3 motorway sites in the West Midlands as described in the next two chapters.

CHAPTER 7 REAL TIME FORECASTING FOR THE M5 MOTORWAY

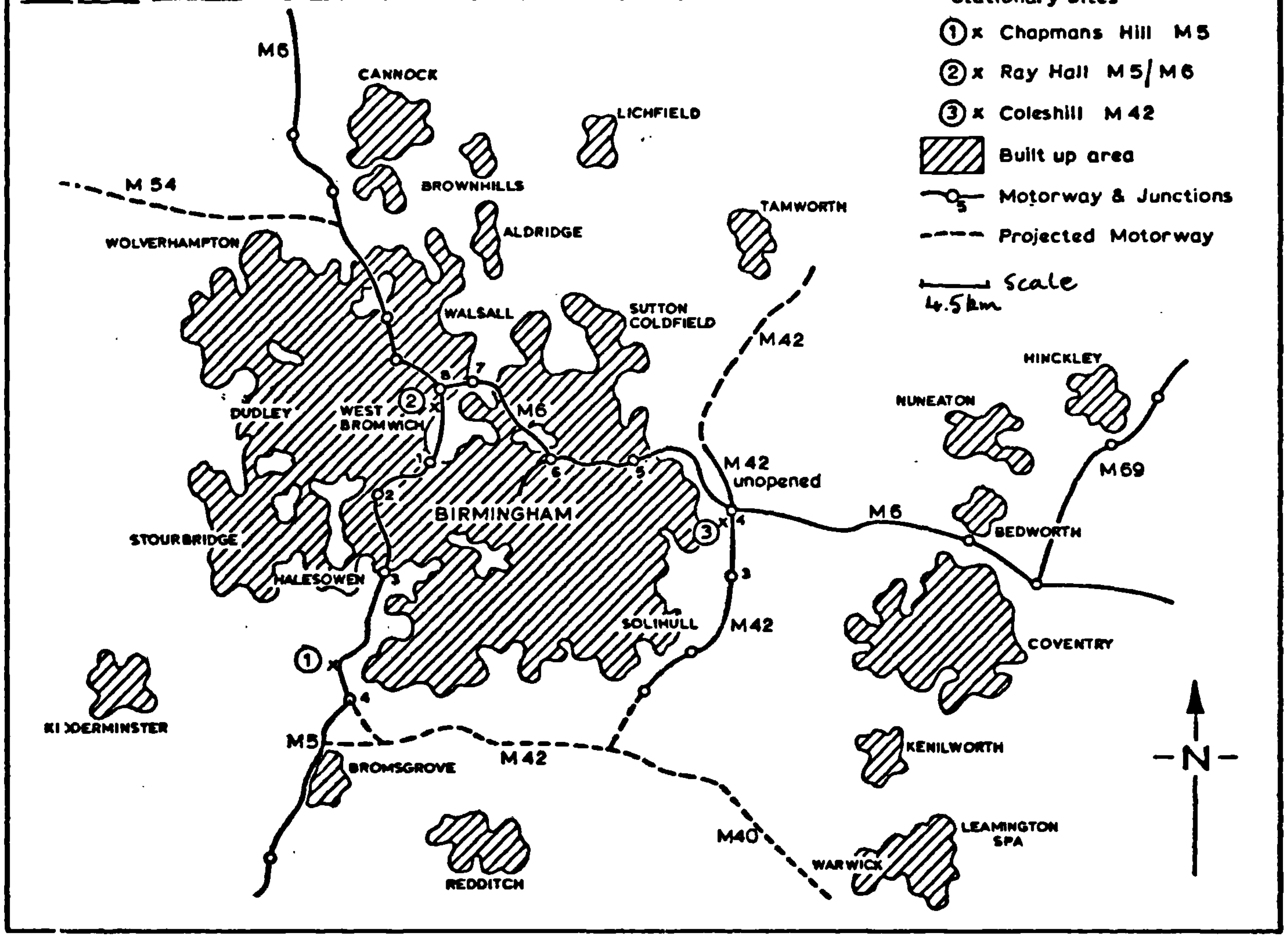
7.1 Introduction

Having calibrated and tested the prediction model presented in earlier chapters using data collected from the M4 motorway, the possibility of testing the model in real time came to fruition during 1982, when three sites were installed on the motorways of the West Midlands as part of a research grant from the Transport and Road Research Laboratory. The system installed was bought commercially from Eagle International Systems Limited who import most of the 'SCAN-16' equipment from Surface System Incorporated, St. Louis, in the United States of America. The experience of installing the site on the M4 was invaluable in deciding upon the configuration of the three sites, two of which were fully operational for the winter of 1982/83. This chapter presents the results for 80 real time forecasts of road surface temperature during that winter. It also presents the results of the monitoring of Road Danger Warnings issued by Elmdon Weather Centre and subsequent salting action by Hereford and Worcester County Council. This is the first time that such a monitoring exercise has been undertaken in Britain. Although it has been possible to test the reliability of the commercially installed Scan equipment, a detailed 'field test' of this equipment is not the purpose of this chapter, which is to show how well the prediction model works in real time, in comparison to the Road Danger Warnings issued by Elmdon Weather Centre.

7.2 The Three West Midlands Motorway Sites

Figure 7.1 shows the location of the three sites that were chosen from a list of 10 cold spots in the West Midlands picked out by local maintenance engineers. Some of the 10 sites were unsuitable because of

FIGURE 7.1 WEST MIDLANDS MOTORWAYS AND SENSOR SITES



projected resurfacing work, and others because of the problem of supplying power and telephone cables to each site. In the past it has often been a 'rule of thumb' to put sensors at cold spots on a road network. This can lead to oversalting if it is not known how much colder these sites are than the rest of the road system. If a thermal map of road surface temperatures is available then the choice of sites becomes less critical, and the cheapest or most convenient sites for power and telephone lines can be selected. The three chosen sites for this study were recognised cold spots in an arc around Birmingham. Subsequent thermal mapping has confirmed these cold spots and it could be argued that only one site is necessary for the whole of the West Midlands now that the thermal map is available. However the sites are not reliable enough to be left in isolation and experience has shown that the spacing of sites chosen is about right. Too many sites can lead to the maintenance engineer being swamped by information. Too few sites can lead to problems if sites are out of action for long periods due to perhaps a telephone line failure.

The problems in choosing representative sites are numerous, however with the advent of thermal mapping, using a vehicle mounted infra-red thermometer, it should be possible to not only find suitable sites but also to reduce the number of sites needed (Sugrue, Thornes and Osborne 1983). As can be seen from Figure 7.1 the motorways around Birmingham pass through both rural and urban areas. The population of the West Midlands conurbation is just over 2.5 million. Oke (1973, 1981) has shown that the maximum size of the urban heat for a European city is approximated by:

$$\Delta T_{u-r(max)} = 2.01 \log P - 4.06$$

For a population of 2.5 million this gives a maximum heat island intensity of 8.8°C which confirms that the maximum observed intensity of 9°C for Birmingham reported by Unwin (1980) for the 10 year period 1965-1974.

The stretches of motorway considered in this chapter do not go through the centre of Birmingham, but undoubtably on nights when the heat island develops we would expect a thermal influence on the urban stretches. Unwin (1980) shows that the nocturnal heat island is at its weakest in winter, and so the warming effect on road surface temperatures is not likely to be more than a degree or two. This is being examined in more detail by Sugrue (NERC Studentship to construct thermal maps of the motorways in the West Midlands).

The three chosen motorway sensor sites are:

7.2.1 Chapman's Hill M5

The M5 south west of Birmingham climbs steadily from Worcester to cross the Clent/Lickey ridge at a height of just over 250 metres. Chapman's Hill presents a steep climb to the top of the ridge and the instrumented site is on a cutting exposed to the west approximately a kilometre from the top of the hill at a height of 200 metres. This stretch of motorway, as far north as Junction 3 on the M5, is maintained by Hereford and Worcester County Council from the maintenance depot at Lydiate Ash. The motorway consists of a three lane dual carriageway and the surface sensors are installed in the slow and fast lanes of the north bound carriageway, as shown in Figure 7.2. The surface sensors measure road surface temperature at about a millimetre below the surface, and also the conductivity between two metal pins flush with the surface. Figure 7.3 shows the dimensions of the sensor and Figure 7.4 shows the installation of a sensor

MONITORING ROAD SURFACE CONDITIONS ON MOTORWAYS IN THE WEST MIDLANDS

FIGURE 7.2

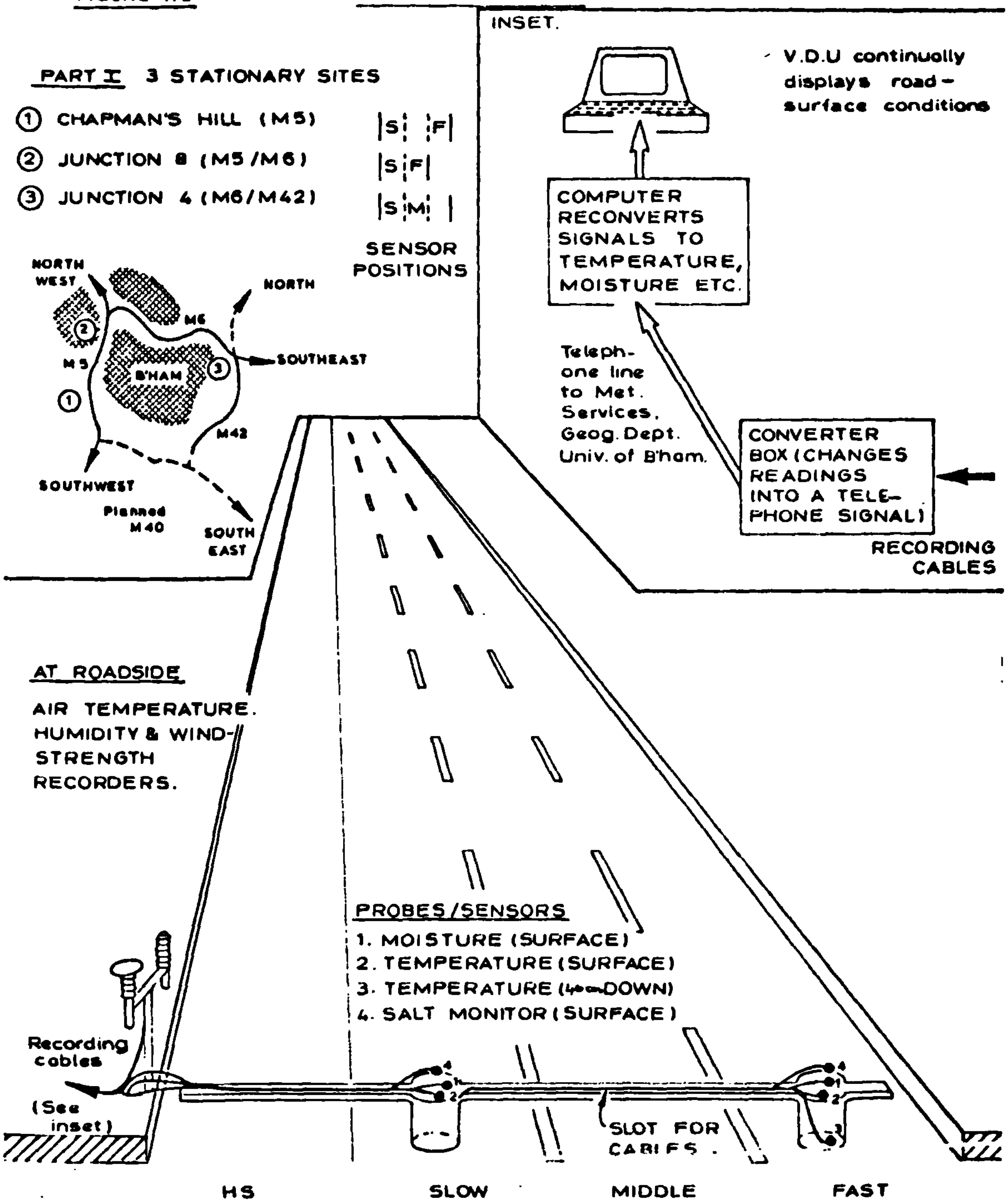


ILLUSTRATION: Chapmans Hill site

FIGURE 7.3 The Scan surface sensor

FIGURE 7.4 Installation of the sensor at 40cm

at a depth of 40 cm. At the side of the motorway air temperature and humidity are measured, as well as wind speed and direction at a height of 2 metres. The instruments are interrogated by a microprocessor contained in a weatherproof box off the motorway. At preset intervals a microprocessor housed in the Meteorological Services Unit at Birmingham University dials up the microprocessor on site using an auto-dialling modem. The data is sent to the University every hour or every half hour depending upon preset instructions, and is shown on a visual display unit, and stored in the microcomputer. The site can be called from the University at any time but the computer is normally left to dial automatically.

This was the first site to be "switched on" during May of 1982 giving a full set of observations during the winter of 1982/83. These will be discussed in detail below, but it should be mentioned that this is the only site where the slow and fast lanes are instrumented, however for convenience the lanes will be compared as slow and fast on the other two sites as well. The results show that there can be significant differences in temperature between the two lanes due to the differing frequency of traffic. The slow lane is warmer than the fast lane most of the time in winter.

7.2.2 Ray Hall M5/M6 Interchange

The M5/M6 interchange at Ray Hall was chosen because of the exposed nature of its fly-overs and elevated sections. The south bound link between the M5 and M6 climbs to approximately 15 metres above the ground in a two-laned elevated section and is instrumented at its highest point with a sensor in both lanes. This gives a total altitude of 122 metres.

A sensor at depth was not possible, but this elevated section gives a useful comparison with the normal carriageway site at Chapman's Hill. Unfortunately due to an administrative error, the Department of Transport did not tell us that this section of road was due for resurfacing during the Autumn of 1982 and the sensors were lost before they were even connected up! They were replaced eventually but did not provide any data until February 1983. One of the sensors is still not working properly due to the singeing of its connecting cable. Therefore, it is only possible in the outside lane to measure either surface temperature or wetness. However because the traffic on both lanes is heavy there is not likely to be as marked a difference between the two surface temperatures as at Chapman's Hill.

This section of the motorway is maintained by West Midlands County Council from their depot at Castle Bromwich.

7.2.3 Coleshill M42

The M42 is the link motorway between the M5 and M6 to the south of Birmingham. However, it is not yet complete and consequently carries little traffic in comparison to the M5 and M6. Also this area to the south east of Birmingham Airport and Solihull is in a "frost hollow" associated with the shallow valley of the river Blythe. Hence the M42 is much colder than the heavily trafficked M6 and indeed this is recognised by West Midlands County Council who spread twice their normal salt application upon it. The Sensors are placed on the slip road to the M6 at a point where the three lane carriageway reduces to two lanes for the slip road at a height of 100 metres. The sensors are in the slow and middle lane and the fast lane is coned off. Beneath the sensor in the middle lane the temperature at a depth of 40 cm is also measured. This slip road is maintained by Warwickshire County Council and hence each of the three sites is maintained by a different County Council. This has been beneficial in that all three counties have been able to see the system in action.

The M42 site provided data throughout the winter of 1982/83, which means that a detailed comparison between the observations from it and the M5 site is possible.

7.3 Comparison of Observations Between the Three Sites

As mentioned above, data from the Ray Hall site did not become available until February 1983, nevertheless a useful comparison of observed minimum road surface, and air temperatures can be made as shown in Table 7.1. The nights between 30th September 1982 and 30th April 1983 have been considered, but as can be seen from the table some data was lost from each sensor due to various communication breakdowns. On average it can be seen that the slow lanes are warmer than the fast lanes by 0.55°C for the M5, and by 0.42°C on the M42. This is due to the effect of traffic keeping the slow lanes warmer, and because the M5 is busier than the M42 the difference is greater on the M5. This average difference between the lane minimum temperatures of about 0.5°C may not seem great but it is significant, as Table 7.2 shows. On individual nights the difference can be up to 2°C, and on several occasions the slow lane sensor stayed above freezing, whereas the fast lane sensor dropped below.

Table 7.1 Mean Minimum Temperatures October - April 1982/83 for the Three Sites °C

Sensor	No. of Nights	Mean	Stand. Deviation
M5 Slow	187	3.01	3.98
M5 Fast	184	2.46	3.82
M5 Air	188	2.81	2.52
M5 40 cm Depth	203	6.59	2.87
M42 Slow	184	2.71	4.04
M42 Fast	188	2.29	4.09
M42 Air	178	3.09	3.86
M42 40 cm Depth	200	6.73	3.14
M5/M6 Slow	45	3.26	3.07
M5/M6 Fast	45	3.06	2.98
M5/M6 Air	45	3.39	2.35

Table 7.2 Comparison of Minimum Lane Temperatures Using a Paired t-Test

Paired t-Test Between	No. of Observ.	Value of t	Significance level
M5 Fast-M5 Slow	183	14.6	0.001
M5 Fast-M5 Air	184	4.4	0.001
M42 Fast-M42 Slow	183	12.7	0.001
M42 Fast-M42 Air	177	8.9	0.001

As far as the maintenance engineer is concerned it is the temperatures in the fast lanes that he is most interested in, as they are the coldest. As far as the meteorologist is concerned it is perhaps the difference between the minimum air and minimum road temperature that has caused most interest. On average the slow lane on the M5 was warmer than the air temperature by 0.2°C, a result which confirms the findings for the M4 discussed earlier. Both the M4 and the M5 are heavily trafficked even at night. However the average air temperature for the M42 was warmer than the M42 fast lane by 0.4°C, which shows that for lightly trafficked roads indeed the surface is colder than the air. The subtracted difference between the minimum road and air temperatures for the M5 and M42 sites are shown in figures 7.5 and 7.6 respectively. It can be seen that the difference DT(A-R) varies with season and is at a maximum towards the end of January. The relationship appears to be sinusoidal, which confirms the findings of Parrey (1969), Ritchie (1969) and Hay (1969). Hay, in the only study of the three that considered a trafficked road, concluded between mid-November and mid-February that there is no significant difference between the minimum road and air temperatures. His results are based on observations from the heavily trafficked slow lane of the M1 near Newport Pagnell, and the results for the M5 slow lane presented here are very similar. However on individual nights the difference between the minimum air and fast lane temperatures is significant and averages can be misleading.

Parrey (1969), for an untrafficked concrete road has related observed DT(A-R) to the length of night in hours (t):

$$DT(A-R) = 0.28t - 2.9$$

FIGURE 7.5 THE DIFFERENCE BETWEEN AIR MINIMUM AND FAST LANE MINIMUM TEMPERATURE FOR EACH WINTER NIGHT 1982/83 M5

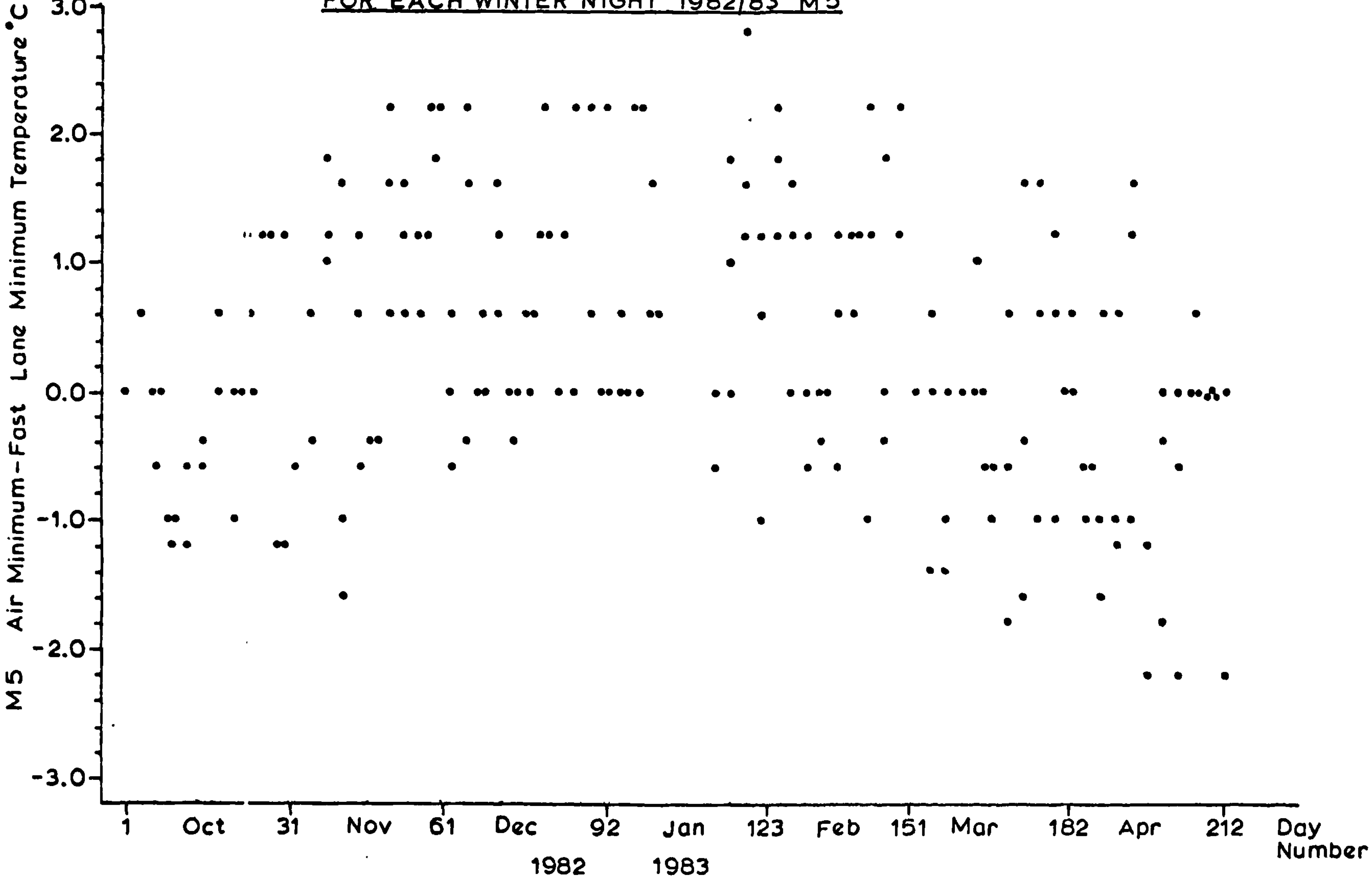
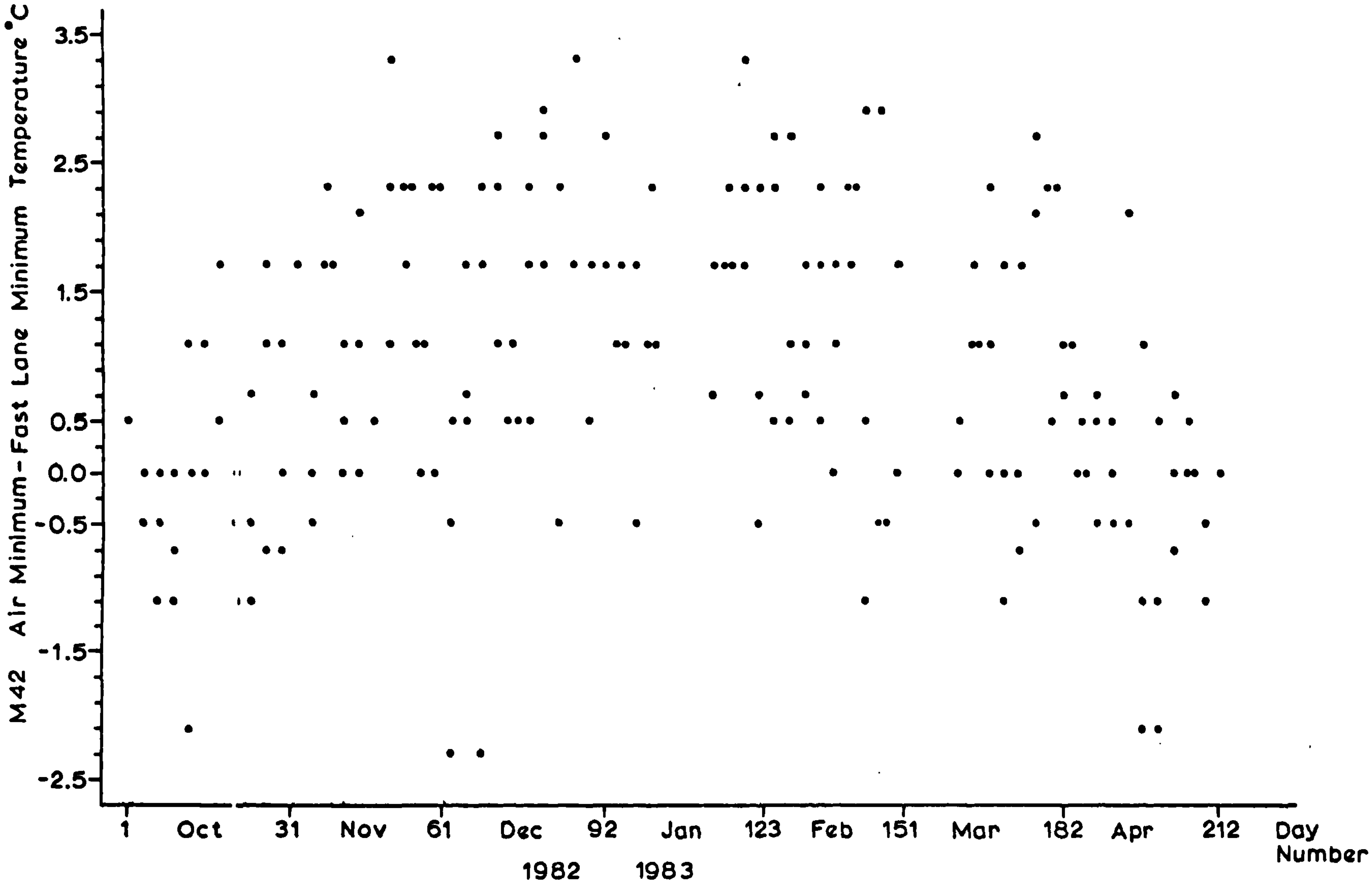


FIGURE 7.6 THE DIFFERENCE BETWEEN AIR MINIMUM AND FAST LANE MINIMUM TEMPERATURE FOR EACH WINTER NIGHT 1982/83 M42



The length of night obviously relates to the time available for outgoing terrestrial radiation, but on the other hand, the longer the night the more the flow of heat from below the surface which balances the radiation loss.

Ritchie (1969) used Fourier analysis to give the equation of line of best fit for DT(A-R) plotted against day of the year where 365 days is conveniently assumed to be close to 360 degrees. The data was for an untrafficked bitumen slab, and the equation is:

$$DT(A-R) = 0.48 + 1.22 \sin x$$

The maximum value is therefore when $\sin x = 1$, i.e. when $x = 90$. Day 1 is assumed by Ritchie to be the first of October and hence the maximum is at the beginning of January, and the minimum at the beginning of July when $\sin x = -1$. A similar equation has been derived for both the M5 and the M42:

$$DT(A-R)M5 = -0.24 + 1.1 \sin x$$

$$DT(A-R)M42 = 0.24 + 1.2 \sin x$$

The equations are very similar in form and hence the shape of the curves are almost identical to Ritchie's curve, however the intercept is different. It seems that the more heavily trafficked the road surface the lower the intercept on the y axis.

Why should this relationship be sinusoidal? Is it because of the length of night or are there any other factors that vary seasonally? An important factor must be the temperature at depth in the road, and for the M5 and M42 we have observations at 40 cm. Figures 7.7 and 7.8

FIGURE 7.7 40 cm TEMPERATURE BELOW THE ROAD SURFACE FOR EACH WINTER NIGHT 1982/83 M5

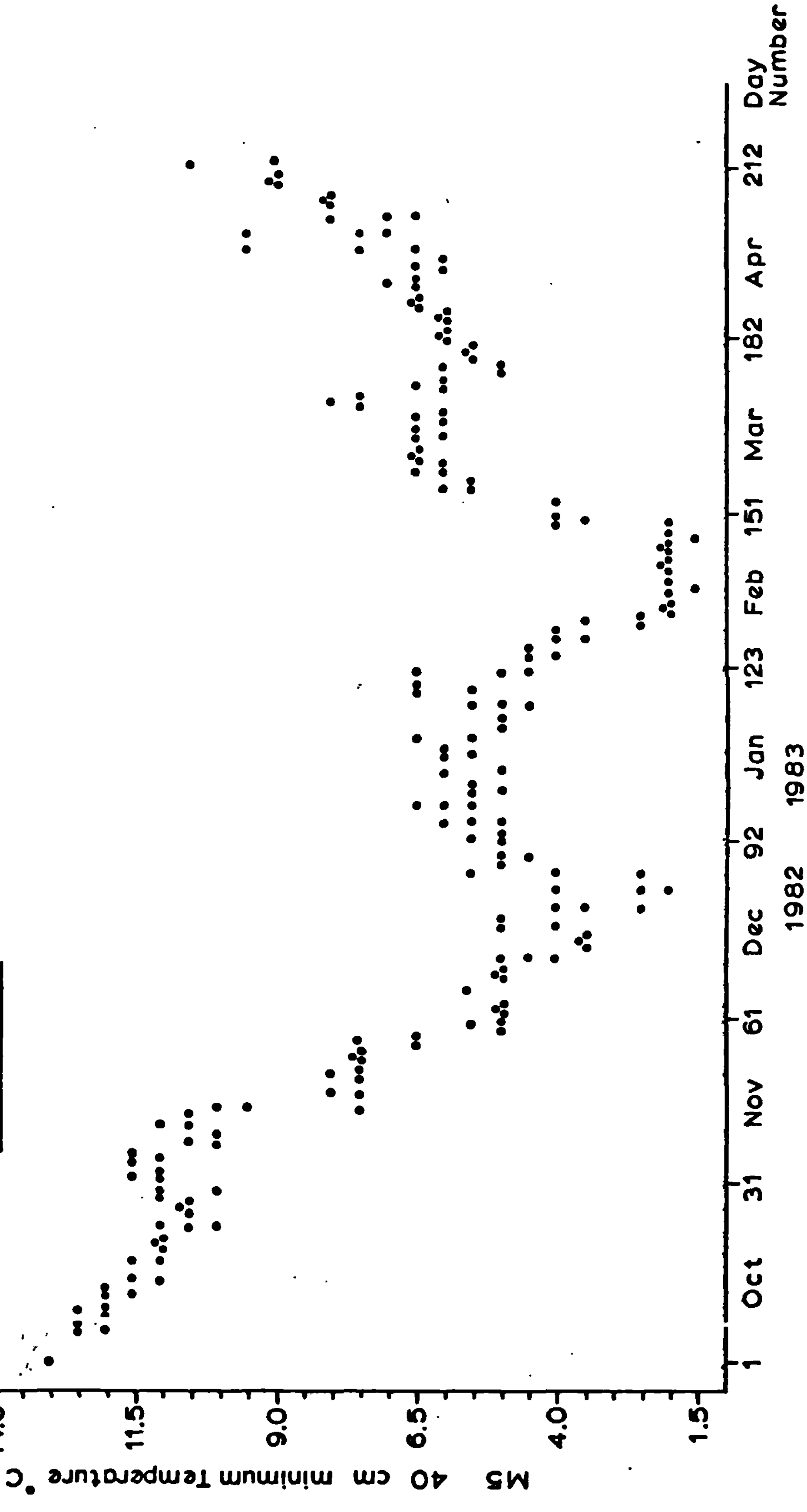
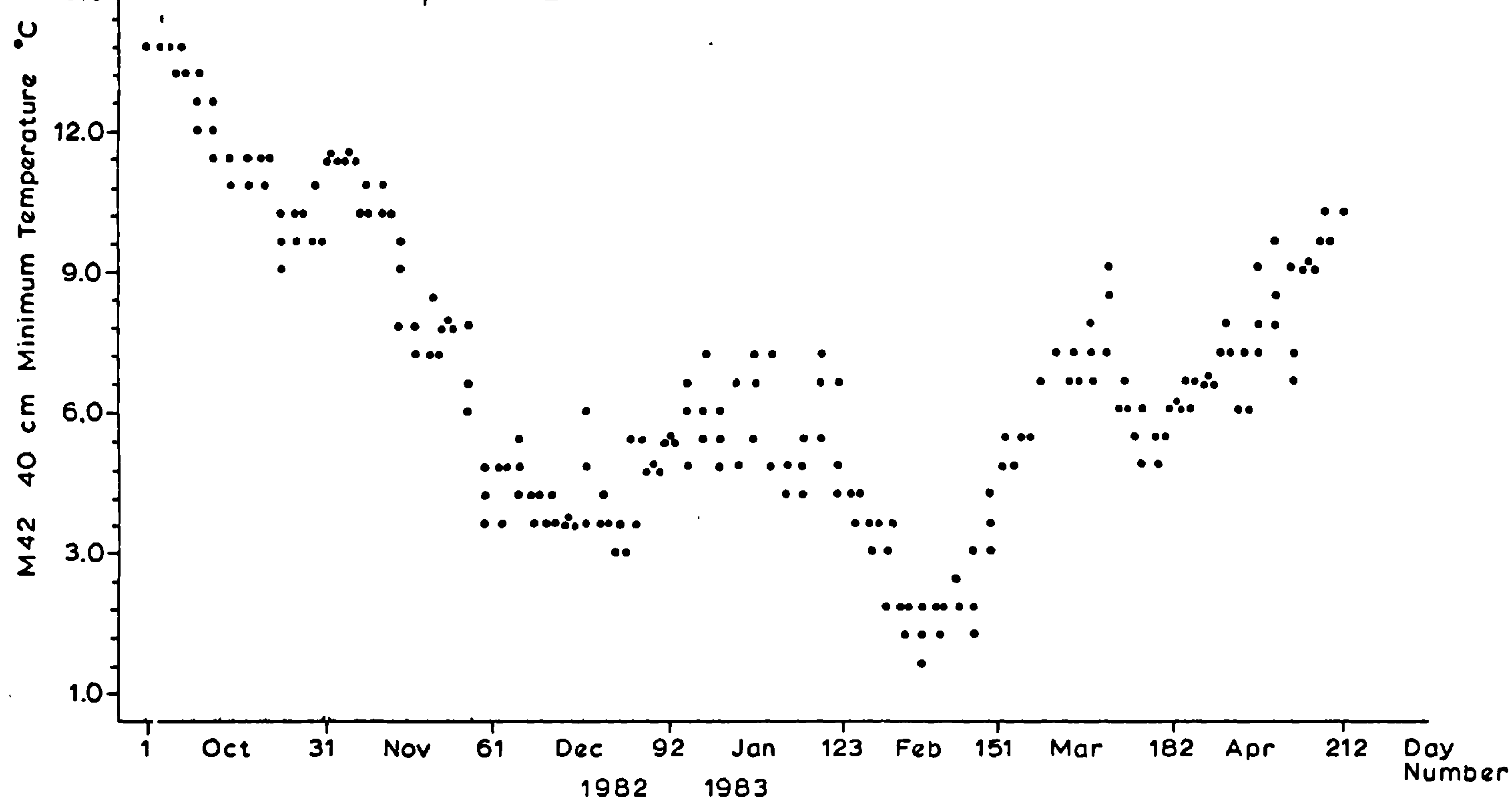


FIGURE 7.8 40 cm TEMPERATURE BELOW THE ROAD SURFACE FOR EACH WINTER NIGHT 1982/83 M 42



show that the temperatures at 40 cm also appear to vary sinusoidally but in opposite phase to DT(A-R). Thus as the temperature at 40 cm drops as the winter progresses so DT(A-R) increases. The equations for the seasonal change in the temperatures at 40 cm are as follows:

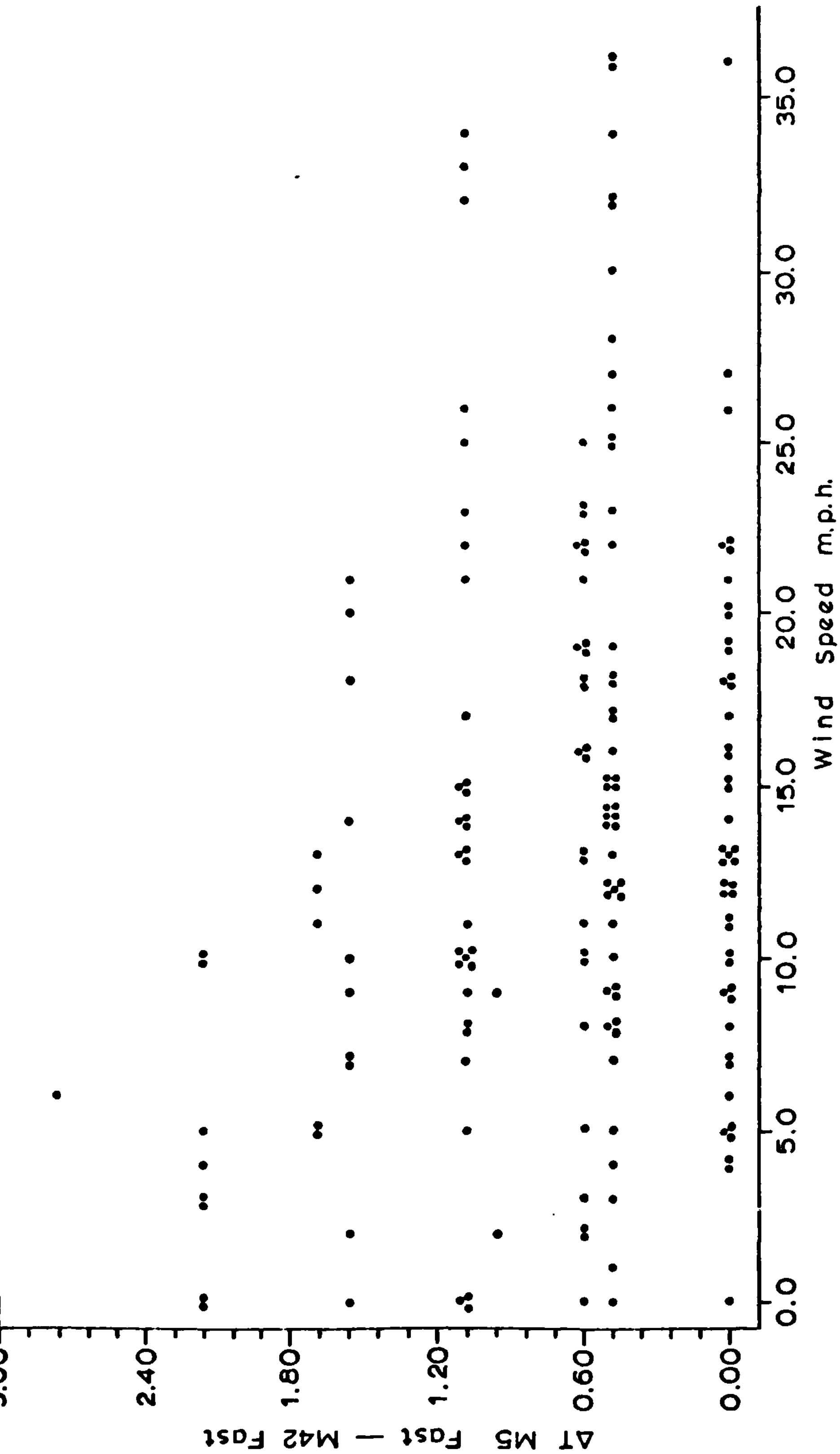
$$T(\text{M4 40 cm}) = 7.9 - 2.62 \sin x$$

$$T(\text{M42 40 cm}) = 8.3 - 3.13 \sin x$$

Thus it can be supposed that as the reservoir of heat stored in the road is reduced as the winter progresses so the minimum road surface temperature is reduced, and DT(A-R) becomes greater. More detailed research is required however to finalise this argument. Another important factor that may account for variations in DT(A-R) on a given night is wind speed as discussed in Chapter 4. The greater the windspeed, the more the mixing, and one would therefore expect that the difference in temperature between the road and the air would be less. Unfortunately windspeed was not recorded at the sites during the winter of 1982/83, although wind sensors have now been installed. Therefore using wind speeds from Birmingham University the correlation between DT(A-R) for the M5 is 0.057, and for the M42 is 0.131; neither of which are significant. Thus it seems that wind speed may not be a controlling factor in the size of DT(A-R), but further research is required.

When examining the differences between the M5 and M42 sites it was hypothesised that due to the effects of altitude, the M42 site would be colder on calm clear nights due to the pooling of cold air; and that the M5 site would be coldest on windy nights due to its greater altitude. Figure 7.9 shows a plot of the absolute values of DT(M5 fast-M42 fast) against windspeed. The correlation coefficient is -0.228 which is

FIGURE 7.9 ABSOLUTE DIFFERENCE IN MINIMUM TEMPERATURES BETWEEN M5 AND M42 PLOTTED AGAINST WINDSPEED



almost significant at the 1% level. Hence windspeed seems important in determining the difference in temperature between the sites. On windy nights the difference is less, as would be expected. Wind direction might also be important in that advection from Birmingham's heat island might cause one of the sites to gain heat. Figure 7.1 showed that the M5 site is to the south-west of the city whereas the M42 site is to the east. With an easterly airsteam one would expect that the M5 site should be warmer, and with a westerly wind the reverse. A northerly airstream might also keep the M5 site slightly warmer than the M42 for similar reasons. Three periods during the winter when the road minimum temperatures were below zero, illustrate this hypothesis; the first was a westerly airstream in late December; the second period was a dominant easterly flow, the third a dominant northerly as shown in Table 7.3.

These three periods confirm the hypothesis, that for cold nights it can be accepted as a rule of thumb that under cyclonic westerly conditions the M5 is likely to be coldest, whereas with anticyclonic northerlies and easterlies the M42 is likely to be coldest. However it must also be remembered that on wet nights the temperature difference between the sites is likely to be less, and hence in cyclonic conditions with associated fronts the differences are likely to be small. For the whole winter the situation is more complicated. Out of the 179 nights when figures are available for both sites, the M5 was colder than the M42 on 50 (28%) nights, warmer on 83 (46%) nights and the same on 46 (26%) of the nights. Thus roughly speaking M42 is colder on about half the nights, the M5 is the same or colder on the other half.

Table 7.4 groups the DT(M5-M42) data according to Lamb's (Lamb 1972) weather types (taken from Climate Monitor) for each night. Lambs weather types have been simplified to just the 7 categories given.

Table 7.3 Wind Direction Versus DT(M5 fast-M42 fast)

Date	M5 fast Min.	M42 fast Min.	DT(M5-M42)	Wind Dir. dominant	Windspeed m.p.h.
17-18D	-2.7	-2.2	-0.5	west	11
18-19D	-3.8	-3.3	-0.5	west	18
21-22D	-3.3	-2.7	-0.5	nor-west	15
22-23D	-4.4	-3.8	-0.6	west	10
23-24D	-1.1	0.5	-1.6	west	11
27-28D	-1.1	0.0	-1.1	west	12
12-13F	-4.4	-0.6	1.6	nor-west	8
13-14F	-6.0	-7.7	1.7	nor-west	6
14-15F	-1.6	-2.7	1.1	east	11
15-16F	-0.5	-0.5	0.0	east	12
16-17F	-3.8	-4.9	1.1	east	11
17-18F	-3.8	-6.6	2.8	east	9
18-19F	-3.3	-4.4	1.1	east	8
06-07F	0.0	0.0	0.0	north	22
07-08F	-1.1	-1.1	0.0	north	15
08-09F	-5.5	-6.0	0.5	north	12
09-10F	-2.7	-4.4	1.7	north	11
10-11F	-2.2	-2.7	0.5	north	13

Table 7.4 Lamb's Weather Type Versus DT(M5-M42)

Weather type	Number of Nights +ve	-ve	DT(M5 fast-M42 fast) same	Total
Cyclonic	21(39%)	18(33%)	15(28%)	54
Anticyclonic	23(64%)	8(22%)	5(14%)	36
Northerly	6	7	3	16
Easterly	0	2	2	4
Southerly	10	3	6	19
Westerly	20(45%)	11(25%)	13(30%)	44
Unclassified	3	1	2	6

Total = 179

This confirms that DT(M5-M42) is much more likely to be positive during anticyclonic conditions, and that the situation is more complicated during cyclonic and westerly conditions.

The data for the M5/M6 interchange given in Table 7.1 is for the period from the middle of March to the end of April and hence the averages are not comparable with those for the M5 and M42. Table 7.5 therefore gives the comparable averages for those 45 nights for all three sites. At this time of year it seems that the M5/M6 site is warmer than the other two sites for all three sensors. It seems that the elevated sections of motorway in the West Midlands are not as cold as might have been expected. This evidence is supported by thermal mapping which has shown that the elevated sections can in fact be warmer than the ordinary motorway for much of the time at night, probably due to the fact that most of the elevated sections are made of concrete and are in urban areas, warmed to some extent by the 'heat island'.

Thus the comparison of the mean between sites has shown that there are significant differences between the three sites. This has been confirmed by thermal mapping. Figure 7.10 shows a typical temperature profile during anticyclonic conditions for the M5 - M6 - M42 motorway.

7.4 The Winter of 1982/83 - Road Danger Warnings and Saltings in Hereford and Worcester

For the winter of 1982/83 it has been possible to monitor the salting of the M5 site, firstly by examining the salting records at the Lydiate Ash maintenance depot, and secondly by examining the "freeze factor" evidence provided by the Scan system. It has also been possible to relate these saltings to the Road Danger Warnings issued by Elmdon weather centre (at Birmingham airport). Let us consider

Table 7.5 Comparison of Minimum Road and Air Temperatures for the Three Sites mid-March to End of April

Site	No. of Nights	Mean	Stand. Deviation
M5 slow	44	3.12	2.91
M5 fast	44	2.69	2.83
M5 air	44	2.35	2.50
M42 slow	43	2.93	2.98
M42 fast	43	2.74	3.08
M42 air	42	2.88	2.44
M5/M6 slow	45	3.26	3.07
M5/M6 fast	45	3.06	2.98
M5/M6 air	45	3.39	2.35

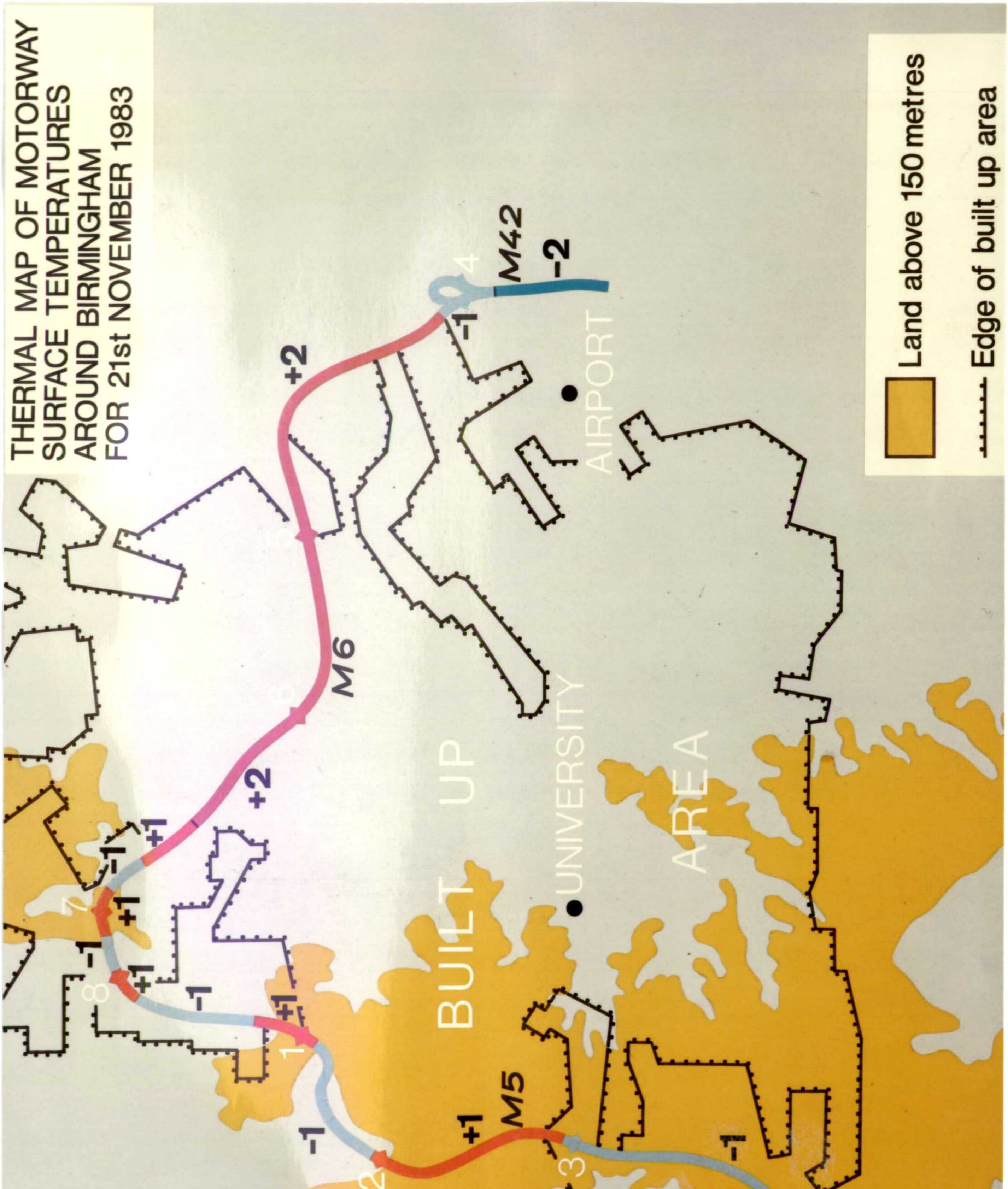

THERMAL MAP OF MOTORWAY
SURFACE TEMPERATURES
AROUND BIRMINGHAM
FOR 21st NOVEMBER 1983
Land above 150 metres
Edge of built up area
BUILT UP AREA
UNIVERSITY
AIRPORT
M6
M5
M42
+2
-2
+1
-1

FIGURE 7.10

each data source in turn.

7.4.1 Salting Records at Lydiate Ash

From the outset it must be said that in Britain and most other countries records of salting operations are notoriously poor. Although the maintenance authorities do attempt to keep a record for legal purposes, in case they are involved in an accident claim regarding an icy road, it is often very difficult to tell when a road was salted, or how many times. The story of Hereford and Worcester is no different. Although they have been extremely helpful in supplying a list of salting occasions for the M5, they have been unable to give exact timings of all the occasions. For instance, information that a road was salted on the 5th of December gives no indication as to whether or not the road was salted on the night of the 4th/5th or the 5th/6th. Going back to the original drivers log books for the salting vehicles sometimes reveals the exact timing, but at other times they are equally vague. The reason for this lack of paper work is simple, the salting crews are far too busy spreading salt to care about filling in a form once the job has been done. Hence they tend to fill in their work sheet at the end of the week when they themselves cannot remember exactly when they went out. Nevertheless it has been possible to reconstruct a detailed list of salting times for most of the days and nights concerned. In future it would obviously be better for a similar exercise to ring up the maintenance depot every morning in winter to ascertain whether or not salt was spread. That would be a time consuming and expensive exercise, but seems to be the only way.

7.4.2 The Scan 'Freeze Factor'

As mentioned earlier in this chapter, the surface sensor used to measure road wetness is a commercial system which has been patented by 'SSI'. Basically the sensor consists of two metal pins flush with the road surface as shown in Figure 7.3, and the conductivity is measured between them by passing a small current through the circuit. If the road is dry then there is a very high resistance to the current, but if moisture is present between the pins then the resistance falls considerably. However in the past it has only been possible to get a qualitative response from such an instrument due to the fact that the resistance is also related to temperature and depth of water. The instrument described in Chapter 4, that was used on the M4 motorway, was found to be very unreliable. A further complication is that the presence of any impurity in the water, including of course salt, also alters the resistance. Does the Scan sensor overcome these difficulties? Only to a limited degree. Firstly an identical pair of pins is contained within the body of the sensor, but to all purposes at the same temperature. Hence the reading on the exposed sensor is automatically compared with the reading of the dry, hidden sensor at the same temperature. This eliminates the temperature problem as long as the temperatures are the same. It could be argued that the temperature at the surface of the road will have greater extremes, but nevertheless the temperature differences are small. Secondly by having such a small sensor, the distance between the pins is only a few millimeters, the problem of depth of moisture is reduced. The sensor used on the M4 was 18 cm in diameter, and of course as the sensor dried out the pattern of moisture remaining between the rings was different on each occasion, thus giving a different reading. By having the pins so close together the results are more predictible. As with all wetness meters they must be installed flush with the surface so as to avoid any pooling of water. The larger the sensor the more difficult this is. The Scan sensor, as shown in Figure 7.3, has to be installed carefully to avoid collecting water. This sensor was patented some years ago, but in the last two years the 'freeze factor' has been introduced. Pleased with the success of detecting moisture it is now claimed by the manufacturers that the sensor is sensitive enough to measure the salinity of the moisture present on the sensor. A scale from 05 to 95 is used to indicate that either the water is pure giving a reading of 95, or that it is 'saturated' in salt to give a reading of 05. Within the next year or so the freeze factor will be further enhanced, ideally to estimate readings of salt in gm/m^2, which is what the maintenance engineer wants to see, but it is very unlikely that the accuracy will be anywhere near sufficient. The accuracy of the current instrument will now be discussed using the observations from the M5 motorway and the salting details from Hereford and Worcester.

The wetness meter gives two indications of surface conditions on the display terminal. One is the freeze factor as already discussed, but also there is a 'status' which is a plain language statement about the road surface condition for instance 'Surface Critical' or 'Dry Alert' or 'Moisture Alert'. Surface Critical means that the road surface temperature is below 0°C and the road is wet. Dry Alert means that although the road is dry the surface temperature is at or below the frost point, and Moisture Alert means that the surface temperature is below 5°C (this threshold can be altered), and obviously the road is wet. The freeze factor then gives supplementary information, if the road is wet, as to approximately how much salt is present. If the freeze factor works it should be possible to observe its drop in value as the road is salted. The night of 1st/2nd February 1983 is a good example of the freeze factor in action. There were snow showers around during the night and according to the salting records the M5 was salted at some time between 0330, and 0630 hrs. This is confirmed by the freeze factor as shown in Table 7.6.

The freeze factor drops from a high value of 95 for the slow lane (and 85 for the fast lane) to a low value of 05 at some time between 0400 and 0630, which coincides with the period when the motorway was salted. It must be noted however that the motorway was in a 'surface critical' state for more than two hours before the motorway was salted.

This sort of information also gives the maintenance engineer an idea of how much salt is still on the road surface from previous applications. Heavy rain can quickly remove salt with the help of vehicle splash, but on the other hand salt can remain for some days on the road if the weather is dry. Interestingly because of the greater amount of traffic in the slow lane, it seems that the salt stays longer on the fast lane. However this information is not so helpful at present because all three lanes are salted at once, but it could save salt on occasions when the fast lane surface temperature just dips below zero, but has sufficient salt left upon it not to require salting.

On the night of the 10/11 February the M5 was salted twice when the freeze factor was already reading 05 in both lanes. A detailed breakdown of the M5 salting will be given in the next section, but for the moment it must be stated that the freeze factor does not always

Table 7.6 Freeze Factor for the Night of 1/2 February 1983 on M5

	slow lane			fast lane		
Time	Status	Surface temp.	Freeze factor	Status	Surface temp.	Freeze factor
0103	drv	-0.5	dry	S.C.	-1.1	85
0203	S.C.	-1.1	95	S.C.	-1.6	85
0403	S.C.	-1.1	95	S.C.	-1.6	85
0503	S.C.	-1.6	35	S.C.	-2.2	35
0633	S.C.	-1.1	05	S.C.	-2.2	25
0919	S.C.	2.2	05	S.C.	1.6	05

S.C. = Surface Critical

Table 7.7 Freeze Factor for the Night of 18/19 February 1983 on the M5

	slow lane			fast lane		
Time	Status	Surface temp.	Freeze factor	Status	Surface temp.	Freeze factor
1635	dry	6.0	dry	dry	5.5	dry
1805	moist	2.7	95	moist	1.6	75
1904	moist	1.6	45	moist	1.1	55
0007	moist	-2.2	45	moist	-2.2	75
0505	moist	-2.7	45	moist	-2.7	35
0606	moist	-2.2	05			
1112	dry	3.3	dry	dry	2.7	dry

behave as predictably as one would expect. For instance on the night of 17/18 December although the motorway was salted three times the freeze factor did not fall below 35 in the fast lane. It is also a problem to decide how low a freeze factor is required to believe that there is sufficient salt on the road to prevent ice formation. Experience seems to point to values below about 25 being sufficient, but further research is required.

One of the ironic things about the spreading of salt on roads is that the salt is hygroscopic. If the relative humidity is above about 80% then an otherwise dry road becomes wet. When the road drys out it is covered with a characteristic white film of rock salt. This can cause considerable oversalting and confusion. The maintenance engineer or one of his assistants, or even the police can be driving along a road, perhaps on an inspection of road surface conditions, and they see that the road is wet. They get back to the maintenance depot and see that their thermometer (on the wall!) reads -1°C, and they rush out to salt the road! In fact the road was already covered in salt! Dry salt causes similar problems because it looks like frost! Experiments using coloured salt have been carried out in America, but it still doesnot get around the wet road problem. Also a wet road is more slippery than a dry road, and so the spreading of salt on an otherwise dry road can be dangerous. Hence more information is needed about the amount of salt on the road surface. Caution is needed when interpreting the Scan freeze factor however because of the hydroscopic nature of salt. For instance the night of 18/19 February was dry, but the humidity was above 85% throughout the night, and there was the possibility of some frost. The M5 was salted at some time between 1630 and 1830 and the resultant freeze factor is shown in Table 7.7.

It would appear that the salt itself is making the sensor read Moist for status, which is misleading and could of course lead the maintenance engineer to salt unnecessarily.

During 1984 the sensor has been improved by adding a precipitation recorder to the side of the road. This should enable a distinction to be made between salt induced wetness, and true precipitation.

Table 7.8 gives the full details for all the nights when salt was spread on the M5 from Lydiate Ash maintenance depot. Altogether there were 39 nights when salt was spread, and 53 actual salting runs. The salting vehicles are set to spread approximately 20 g/m^2 and a typical run will spread about 30 tonnes of salt on the motorway. It is not easy to say how many of the 53 runs were unnecessary or indeed how many more runs should have been made, but with the benefit of hindsight it is possible to make an approximation. First we will examine the number of Road Danger Warnings issued by Elmdon.

7.5 Road Danger Warnings Issued to Hereford and Worcester from Elmdon

Each year Hereford and Worcester pay the small sum of approximately £300 to the Meteorological Office for the supply of Road Danger Warnings from Elmdon. Whenever driving conditions are likely to be affected by the weather, including fog and wind as well as ice and snow, Elmdon ring the maintenance depot at Warndon and the maintenance engineer decides what action, if any, to take. During the winter of 1982/83 Hereford and Worcester received 102 Road Danger Warnings out of 171 days between October 22nd when the first one was issued, and 19th

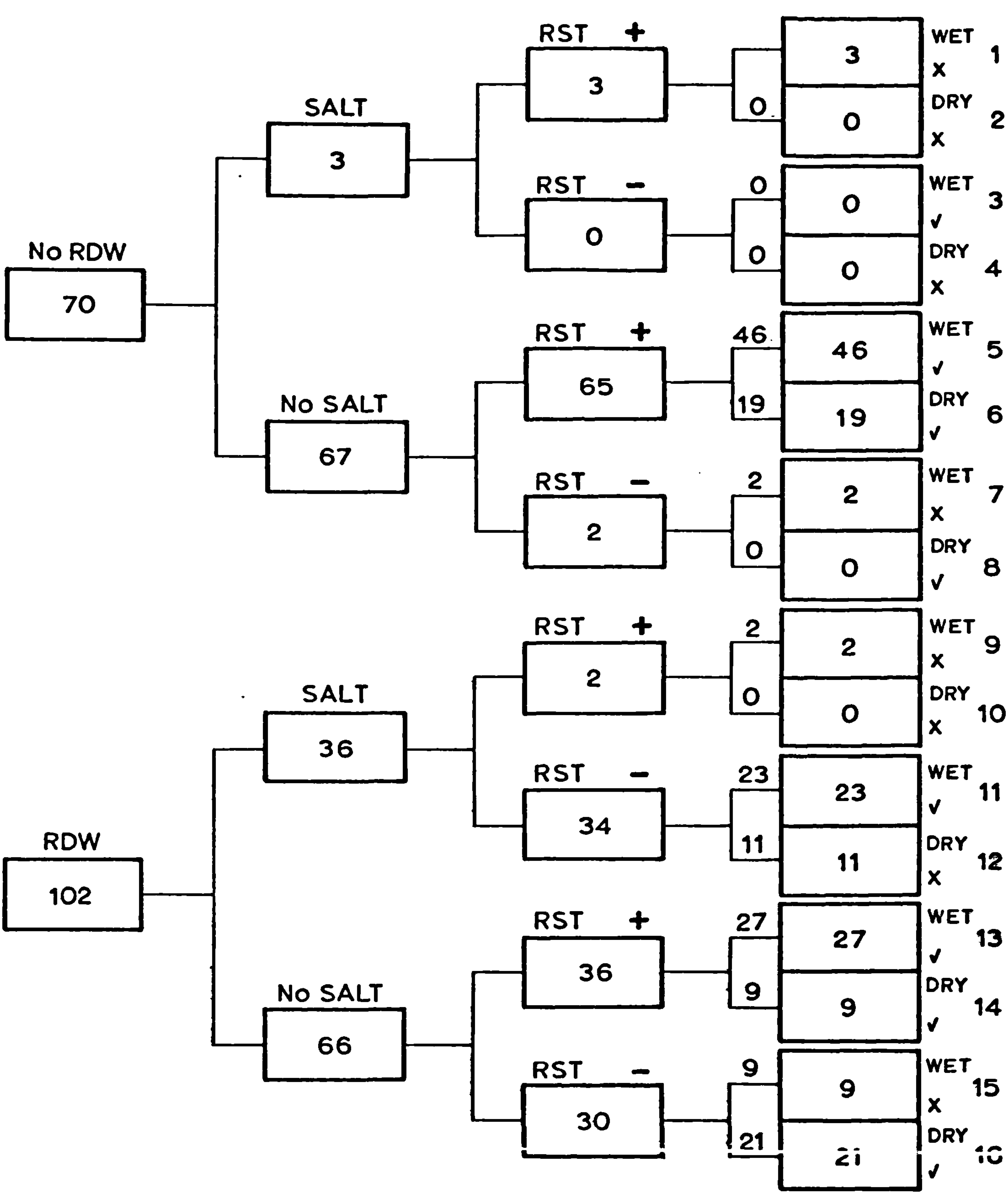
Table 7.8

Salting Times from Lydiate Ash 1982/83 for M5

	Date	Day	Time		Date	Day	Time
1	15-16N	(15)	1730-1930	27	01-02J	(2)	0200-0345
2	26-27N	(27)	0300-0600	28	06-07J	(7)	0500-0600
3	27-28N	(27)	1700-1900	29	07-08J	(8)	0500-0645
4		(28)	0100-0300	30	12-13J	(13)	0315-0530
5	28-27N	(28)	1730-1930	31	13-14J	(14)	0100-0300
6		(28)	1945-2100	32	18-19J	(18)	2145-0000
7		(29)	0400-0500	33	19-20J	(20)	0245-0500
8	29-30N	(29)	1730-1930	34			
9		(30)	0530-0615	35	28-29J	(29)	0830-0930
10	30-01D	(30)	1530-1830	36		(29)	1115-1215
11	10-11D	(11)	0140-0330	37	29-30J	(29)	1530-1600
12		(11)	0800-0900	38	30-31J	(31)	0130-0330
13	11-12D	(12)	0230-0330	39		(31-1)	0915-1400
14		(12)	1100-1200	40	01-02F	(2)	0330-0630
15	12-13D	(12)	1730-1845	41	06-07F	(7)	0930-1030
16		(12)	1945-2045	42	07-08F	(8)	0215-0415
17	13-14D	(13)	1215-1330	43	09-10F	(9-10)	2300-0030
18		(13)	2000-2115	44	10-11F	(10)	1945-0000
19		(13)	2300-0000	45		(11)	0215-0345
20	16-17D	(17)	0130-0345	46	11-12F	(12)	0530-0700
21	17-18D	(17)	2015-2115	47	12-13F	(13)	0600-0630
22		(18)	0215-0445	48	18-19F	(18)	1630-1830
23		(18)	0745-0845	49	19-20F	(19)	1630-1800
24	22-23D	(22)	1800-1930	50	21-22M	(22)	0200-0415
25	23-24D	(23)	1800-1845	51	02-03A	(2)	2130-2330
26	27-28D	(28)	0530-0715	52	03-04A		
				53	04-05A		

April which was the last. The warnings are not meant to tell the maintenance engineer when to salt, merely to advise him as to the likelihood of ice or snow. The winter of 1982/83 produced very little snow in The West Midlands, and hence the vast majority of the warnings related to ice. Normally the weather centre at Elmdon does not keep detailed records of it s Road Danger Warnings and hence it was difficult to extract from various bundles of paper the full number of Warnings issued to Hereford and Worcester. It was therefore necessary to cross check the Warnings issued with the warnings received at Warndon Depot. A diary is kept at Warndon of Warnings received during normal working hours, but at other times and at weekends and holidays the depot relies upon telex transmissions which unfortunately are sometimes undated.

Figure 7.11 is as complete a record as it has been possible to make giving all the possible alternative decisions for a given night, summed for the winter. The resulting picture is somewhat chaotic, but facilitates an analysis as to whether or not the road surface temperature on the M5 fell to, or below 0°C (column 3), and whether or not the M5 was wet or dry (column 4). Of the 102 nights when Road Danger Warnings were issued the roads were only salted 38 times. This shows that there is a considerable input by the maintenance engineer to the decision making process. Five years ago the difference would not have been as large, because the maintenance engineers were not under pressure to save money to the same extent as they are today. In the past salt was relatively cheap and authorities would have salted the roads had there been the slightest thought of ice or snow in a Road Danger Warning. Hence the maintenance engineer's recent interest in measuring road surface conditions so the salt is only spread when necessary.



+ Positive
− Negative

Decision { ✓ Correct
X Incorrect

FIGURE 7.11

WINTER 1982/83 M5 SALTING v ROAD DANGER WARNINGS

Hereford and Worcester claim to have halved their average number of salting trips over the last few years (personal communication D. Wood, Group Engineer for Maintenance, Hereford and Worcester County Council). However has this reduction been beneficial, or are our roads more dangerous to drive upon? Table 7.9 gives a monthly breakdown of the number of nights for which data was available for each month categorised into the 16 possible outcomes shown in Figure 7.11. The table also shows the number of Road Danger Warnings and the number of nights salting for each month. It can be seen that 29 (74%) out of the 39 saltings were carried out in the three months of December, January and February, whereas within the period only 57 (56%) of the Road Danger Warnings were issued. In March and April the motorway was only salted 4 times despite 29 Road Danger Warnings. Figure 7.11 shows that of the 66 nights when no salt was spread but a Road Danger Warning was issued, on 30 of those nights the road surface temperature did fall to zero, and on 9 of those nights the road surface was wet. It could be argued by Hereford and Worcester that on those nights they did not salt because there was already sufficient salt down from previous saltings. Table 7.10 examines those 9 nights in more detail.

Of the 9 nights in question salt was only present on 4, although of the other 5 nights probably only 2: the 14/15 November and 14/15 March were really dangerous. The night of 15 November certainly caught Hereford and Worcester napping, as it did many other authorities, and several accidents were reported in the press.

Thus of 66 nights when Hereford and Worcester decided not to salt despite the issue of a Road Danger Warning, they were correct as far as the M5 sensors were concerned, on all but 5 nights. This type of error is most serious however and obviously can lead to road

Table 7.9

Monthly Breakdown of Saltings and Road Danger Warnings Issued to Hereford and Worcester Classified According to Figure 7.11

	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	Total
1		1		2				3
2								
3								
4								
5	5	5	9	11	2	8	6	46
6	6	4	2	3		2	2	19
7				1	1			2
8								
9				1			1	2
10								
11		1	8	7	4	1	2	23
12		4	1	1	5			11
13		5	5	1	2	9	5	27
14	3		1	1	1	2	1	9
15		3	1		2	3		9
16			4	2	10	2	3	21
N	14	23	31	30	27	27	20	172
RDW	3	13	20	13	24	17	12	102
SLT	0	6	9	11	9	1	3	39

N = Number, RDW = Road Danger Warnings, SLT = Saltings

Table 7.10 An Examination of 9 Nights When a RDW was Issued and the RST Fell to Zero With a Wet Road Surface and No Salt was Spread

Date	Fast Lane Min. Temp.	Ice	Comments
13-14 Nov.	0.0°C	Yes	At 0.0° for 2 hours in both lanes and no salt had yet been spread
14-15 Nov.	-1.1	Yes	Temperatures below zero for more than 4 hours and still no salt
25-26 Nov.	0.0	No	Only 0.0° for an hour and still some salt around from the preivious saltings on 15-16 Nov.
21-22 Dec.	-3.3	No	Plenty of salt still down
02-03 Feb.	-1.6	No	Plenty of salt
04-05 Feb.	-0.5	No	Plenty of salt
14-15 Mar.	-0.5	Yes	Road had not been salted for 20 nights
24-25 Mar.	-1.1	Yes	No salt detected but slow lane dry
25-26 Mar.	-1.6	Yes	No salt detected but slow lane dry

Table 7.11 The Number of Nights That the Minimum Temperature Fell to Certain Thresholds on the Fast Lane of the M5

Range	No. of Nights
0.0 °C	11
-0.1→-1.0	11
-1.1→-2.0	18
-2.1→-3.0	13
< -3.1	13
	66

accidents. The other probably more dangerous error is when no Road Danger Warning is issued and the road is not salted, but the road temperature falls to zero. This does not happen very often because Elmdon issue so many Road Danger Warnings. However Figure 7.11 shows that on two occasisons this did happen. On the 23-24 January the temperature fell to -0.5°C in the fast lane and the road was wet. There was not sufficient salt down to prevent freezing. On the 27-28 February the road temperature fell to 0.0°C but there was still plenty of salt left on the road. Thus there were 11 nights during the winter of 1982/83 when the M5 was not salted but the road was wet and the temperature fell to zero or below. Of those eleven nights probably three were extremely dangerous.

The other type of error as far as salting is concerned is the spreading of salt when it is unnecessary. This is costly in terms of labour, the salt itself and of course vehicle corrosion. Of the 39 nights when salt was spread, on 5 nights the temperature stayed above zero; and of the remaining 34 nights when the temperature dropped to zero, on eleven nights the road remained dry. Hence on 23 nights the decision was apparently correct and on 16 nights incorrect. At a cost of about ten thousand pounds per salting night this amounts to £160,000. On top of this it can be argued that of the 23 nights when the maintenance engineers decision was correct to salt, that sufficient salt might already have been present from previous saltings. However there is a limit to this argument as an incorrect salting one night could save a salting on another night. Hence it is very difficult to split those 23 saltings into necessary and unnecessary ones. However on ten nights Hereford and Worcester salted the M5 more than once and it is possible to critise this action on some nights. Altogether 53 salting trips were made on the 39 nights. On 5 of the multiple salt nights the road remained dry, and on one the temperature stayed well above zero (minimum 3.8°C). Eight of the multiple salt nights were in the month before Christmas and one can only suppose that the drivers were seeking overtime payments to boost their Christmas pocket money! Of the 23 salting trips it can be shown that only 28 (53%) were necessary in terms of temperature and wetness alone. Of those 28, 5 salting trips were repeat runs on the same night. This gives weight to the oft quoted hypothesis that at the very least half the salt spread in Britain is done so unnecessarily.

In conclusion of this section it can be stated that there is much room for improvement in both the issue of Road Danger Warnings and in the decision as to whether or not to spread salt. The figures presented for the M5 are of course only for one location on Chapman's Hill, but nevertheless they are as close as one is ever likely to get to the truth. Maintenance engineers are in a difficult position, on the one hand being presented with rather vague Road Danger Warnings, and on the other hand being forced to limit spending on winter maintenance. It is no wonder that they are trying to justify the installation of automatic road sensors to their council committees.

Finally Figure 7.12 gives a breakdown of the Road Danger Warnings versus observed road temperatures, taken from Figure 7.11. It can be seen that on 38 nights the road surface temperature remained above zero, when a Road Danger Warning was issued. Of the remaining 64 nights although the temperature fell to zero, on 32 nights the M5 remained dry. On only two nights were they caught out and the road temperature

FIGURE 7.12 Road Danger Warnings (Elmdon) versus Road Surface Temperature for 172 Nights between October 22nd 1982 and April 21st 1983 for Chapman's Hill M5 Fast Lane

		Elmdon Road Danger Warning		
		YES	NO	TOTAL
Negative	Road Surface Temp.	64 a	2 b	66
Positive	Road Surface Temp.	38 c	68 d	106
	TOTAL	102	70	172

FIGURE 7.13 Model Predicted Minimum Road Surface Temperature versus Actuals for Chapman's Hill Fast Lane M5 for 80 nights During Winter 1982/83 When the Model was run

		Model Road Danger Warning		
		YES	NO	TOTAL
Negative	Road Surface Temp.	37 a	4 b	41
Positive	Road Surface Temp.	2 c	37 a	39
	TOTAL	39	41	80

fell to zero without being forecast, but this is not surprising in that 102 Road Danger Warnings were issued in a relatively mild winter.

7.6 The Performance of the Model in Predicting M5 Temperatures

The prediction model was run in real-time for 80 nights during the winter and Figure 7.13 shows that the model was correct on 74 of those nights in terms of predicted minimum temperature being above or below zero. However on 4 nights the model predicted that the road temperature would not fall below zero when it did. This is a larger error than for the Road Danger Warnings, but this is to be expected in that on only two nights did the model predict that the road temperature would fall to zero when it didnot. In other words the model is not over cautious like the Road Danger Warnings. If the four cells in Figures 7.12 and 7.13 are labelled a, b, c and d as shown then the aim of any forecasting method is to reduce the size of b and c. One way to reduce b, which is the most serious of the two errors, is to increase the size of c; reducing the number of accidents by increasing the amount of salt spread. To take it to an extreme b could be reduced to zero by issuing Road Danger Warnings every night. As far as the model is concerned it is obvious that the only way to reduce b and c is to increase the accuracy of prediction. The root mean square error for the 72 forecasts when the actual minimumroad surface temperature was less than 5°C is 1.5°C and the standard deviation is also 1.5°C, hence 5% of the forecasts can be expected to be outside the range +/-2*s.d. = 3.0°C. If the forecast is for the minimum to be 1.0°C then, using the probability that 68% of the forecasts are likely to be within one standard deviation, and 32% outside that range, then 16% are likely to be zero or below. This is merely confirming how difficult it is to forecast temperatures around a threshold such as zero °C. Table 7.11 shows the distribution of minimum temperatures recorded on the fast lane of the M5.

It can be seen that on 11 nights the minimum temperature was 0.0°C and that on 40 nights the minimum temperature did not fall below -2.0°C. This is a problem of the British climate, the temperature falls to zero often enough, but not for long. This makes the prediction as to whether or not the road temperature will fall to zero more difficult.

Nevertheless the model is a considerable improvement on the Road Danger Warnings issued for the M5. In order to overcome the problems associated with just giving one minimum temperature forecast, it is proposed in future to give an optimistic and a pessimistic forecast. Thus the maintenance engineer will recieve two forecast graphs of predicted minimum road surface temperature, (1) optimistic, based on weather conditions combining to keep the road temperature warmer than expected; and (2) pessimistic, when the weather conditions combine to reduce the road minimum temperature. On some nights both forecasts might be similar, for instance if there is no cloud and little wind, the forecast errors are likely to be small for those two variables. However if for instance a cold front is moving through, then each forecast will represent a different timing of the clearance of cloud behind the front. The optimistic forecast will be based on the front not clearing through thus keeping temperature up, whereas the pessimistic forecast will be based on the front moving through quicker than expected, giving clearing skies and colder air temperatures.

Returning to Figure 7.13 the nights when the model was in error - cells b and c, are set out in Table 7.12. From the table it can be seen that three of the nights when the model led to error b, the minimum road surface temperature only fell to 0.0°C, and on two of those nights the road was dry.

7.7 Overall Performance of the Model

Table 7.13 gives the actual fast lane minimum road surface temperature for the M5 for each of 80 nights when the model was run, plus the predicted minimum temperature. The distribution of errors is shown in Table 7.14, and remarkably they seem to be equally distributed about zero error. The effect of traffic which offset the predicted retrospective temperatures for the M4 motorway, discussed in Chapter 6, is not so important for the fast lane of the M5 motorway. Most of the forecasts included in the analysis were run during the afternoon of the day in question. It was usual to wait until about 1500 hrs before running the forecast model but each day varied according to computer availability and work pressure.

Overall the model gives every confidence that it can reproduce the varying influences of wind, cloud, humidity and air temperature upon road temperatures. However some improvements to the model used in this trial have already been made. As well as a prediction of the road surface temperature the maintenance engineer also wants to know when the road is likely to be wet, and the timing of precipitation. The timing of precipitation is important in that salt may be washed off the road. Hence to transform the prediction model into a Road Danger Warning one has to add several other pieces of information as discussed in the next chapter.

Table 7.12 Data for the Nights When the Model Gave Errors b and c

Error b

Date	Actual Min.	Predicted Min.	DT(A-R)	Surface
13-14 Nov.	0.0	3.1	-3.1	wet
03-04 Dec.	0.0	0.5	-0.5	dry
09-10 Jan.	0.0	2.3	-2.3	dry
04-05 Feb.	-0.5	1.0	-1.5	wet

Error c

02-03 Dec.	2.2	-1.1	3.3
23-24 Feb.	1.6	-0.5	2.1

Table 7.13

Actual Minimum Road Surface Temperatures for the Fast Lane of the M5 Compared with the Predicted Minimum for 80 Nights During the Winter of 1982/83

Date	Actual Min.	Predicted Min.	ΔT_{Ac-Pr}	Date	Actual Min.	Predicted Min.	ΔT_{Ac-Pr}
22-23O82	3.8	3.5	0.3	16-17D82	-2.2	-1.1	-1.1
23-24O82	1.6	1.7	-0.1	17-18D82	-2.7	-2.0	-0.7
26-27O82	2.7	6.7	-4.0	18-19D82	-3.8	-2.9	-0.9
27-28O82	3.8	2.2	1.6	19-20D82	0.5	3.2	-2.7
28-29O82	6.6	1.2	4.4	20-21D82	0.5	0.9	-0.4
				21-22D82	-3.3	-1.3	-2.0
01-02N82	9.3	10.7	-1.4	23-24D82	-1.1	0.0	-1.1
02-03N82	10.4	9.3	1.1				
03-04N82	10.4	9.6	0.8	06-07J83	0.0	0.0	0.0
06-07N82	6.0	7.9	-1.9	09-10J83	0.0	2.3	-2.3
08-09N82	6.6	7.4	-0.8	17-18J83	1.1	1.7	-0.6
09-10N82	7.7	6.6	1.1	18-19J83	-1.1	-2.4	1.3
10-11N82	7.7	6.1	1.6	21-22J83	3.8	1.5	2.3
12-13N82	3.3	2.9	0.4	22-23J83	2.2	2.0	0.2
13-14N82	0.0	3.1	-3.1	28-29J83	3.8	4.0	-0.2
19-20N82	0.5	1.8	-1.3	29-30J83	0.0	-0.1	0.1
20-21N82	4.9	6.2	-1.3	20-31J83	-1.1	-1.7	0.6
21-22N82	1.6	3.9	-2.3	31-01F83	1.6	1.7	-0.1
22-23N82	3.3	3.5	-0.2				
23-24N82	1.1	1.0	0.1	01-02F83	-2.2	-0.8	-1.4
24-25N82	2.2	2.8	-0.6	02-03F83	-1.6	-0.5	1.1
25-26N82	0.0	0.0	0.0	03-04F83	-4.9	-3.2	1.7
26-27N82	-2.2	-1.6	-0.6	04-05F83	-0.5	1.0	-1.5
27-28N82	-2.2	-3.8	1.6	05-06F83	1.1	0.3	0.8
28-29N82	-1.6	-1.9	0.3	08-09F83	-5.5	-3.1	-2.4
29-30N82	-2.2	-3.0	0.8	09-10F83	-2.7	-4.6	1.9
30-01D82	0.0	-0.5	0.5	10-11F83	-2.2	-2.1	-0.1
				11-12F83	-2.7	-3.4	0.7
01-02D82	1.6	0.7	0.9	12-13F83	-4.4	-3.0	-1.4
02-03D82	2.2	-1.1	3.3	15-16F83	-0.5	-1.4	0.9
03-04D82	0.0	0.5	-0.5	16-17F83	-3.8	-4.0	0.2
04-05D82	4.9	1.1	3.8	18-19F83	-3.3	-4.6	1.3
05-06D82	-1.1	-3.0	1.9	20-21F83	2.7	2.7	0.0
06-07D82	-1.1	-2.5	1.4	23-24F83	1.6	-0.5	2.1
07-08D82	2.2	5.9	-3.7				
08-09D82	0.5	1.0	-0.5	21-22M83	-0.5	0.0	-0.5
09-10D82	1.1	0.9	0.2	22-23M83	2.7	0.3	2.4
10-11D82	-2.7	-2.0	-0.7	23-24M83	2.7	1.7	1.0
11-12D82	-1.6	-1.8	0.2	24-25M83	-1.1	-0.7	-0.4
12-13D82	-0.5	0.0	-0.5	25-26M83	-1.6	-0.0	-1.6
13-14D82	-2.2	-3.5	1.3	27-28M83	-2.2	0.0	-2.2
14-15D82	2.7	4.3	-1.6	28-29M83	2.2	0.3	1.9
15-16D82	2.7	3.1	-0.4				

Table 7.14

Forecast Accuracy Between Given Ranges for 80 Nights

-3.6 deg.C	-3.5 → -2.6	-2.5 → -1.6	-1.5 → -0.6	-0.5 → 0.5	0.6 → 1.5	1.6 → 2.5	2.6 → 3.5	3.6+
2	1	8	15	25	15	10	2	2

CHAPTER 8 CURRENT AND FUTURE DEVELOPMENTS OF THE MODEL

8.1 Introduction

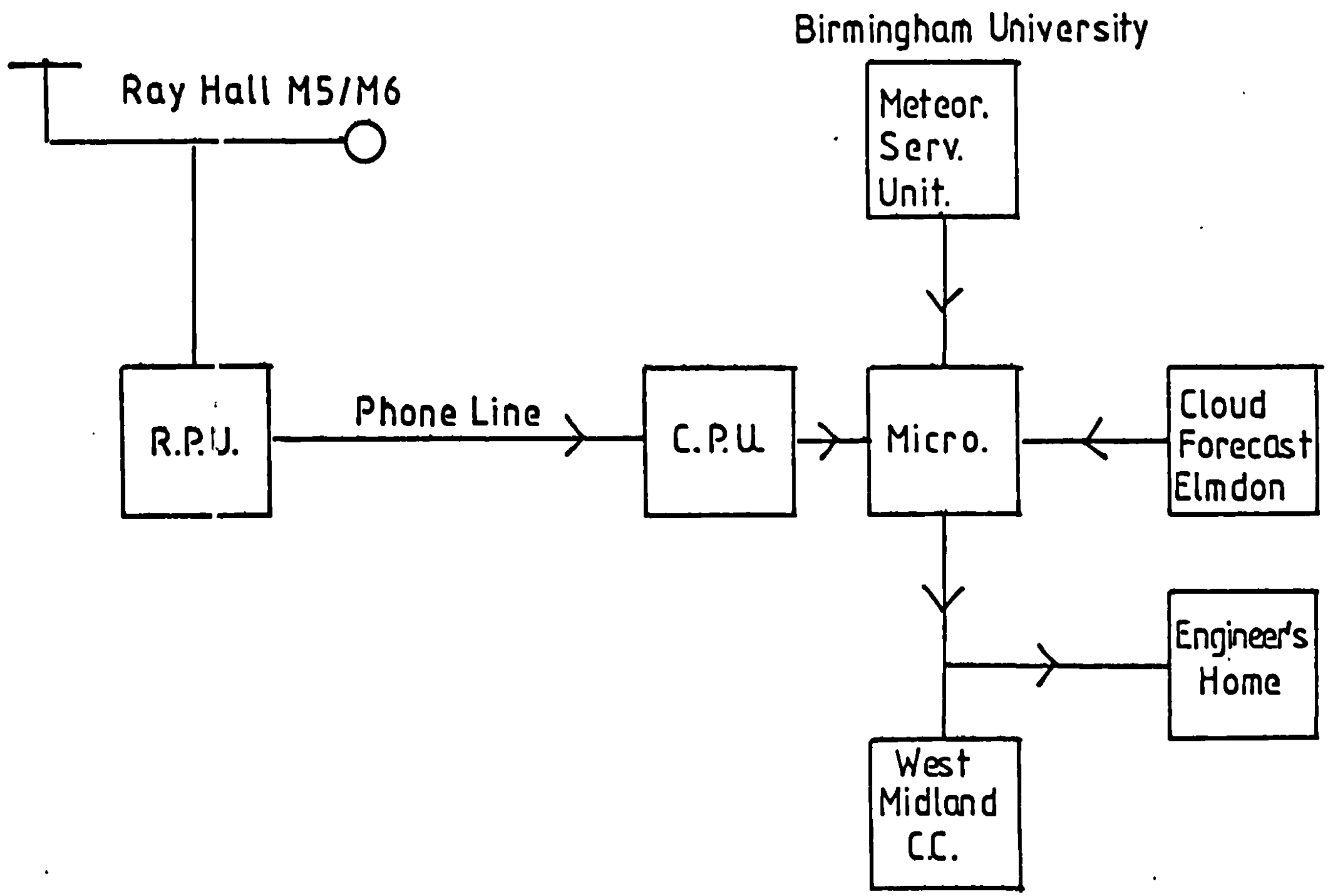
The aim of this thesis, as set out in Chapter 1, is to produce an improved form of Road Danger Warning to be issued to maintenance authorities. During the winter of 1983/84 an experimental graphical Road Danger Warning was issued to West Midlands County Council, based on the model presented in this thesis. It is clear from initial results that the maintenance engineers much prefer this type of Road Danger Warning. Figure 8.1 shows the present channels of communication that translate the observed road surface temperatures into a 24 hour forecast that is received in the maintenance engineers home. Figure 8.2 shows an example Road Danger Warning in graphical form. Basically there are three stages in the production of these warnings: collection, processing and dissemination. Each will be considered in turn.

8.2 Data Collection

The West Midlands County Council are responsible for the salting of the M5/M6 interchange at Ray Hall as outlined in Chapter 7. This site was therefore chosen for the production of trial Road Danger Warnings. Thermal mapping has shown that this site is colder than the M6 stretch to the east, and as cold as the Sandwell valley stretch of the M5 to the south west. Hence the site is representative of the coldest temperatures likely to be found on the West Midland's M5 and M6 stretches of motorway.

The site is interrogated automatically every hour by a micro-computer based at Birmingham University, and the data is stored as

FIGURE 8.1 Experimental Road Danger Warnings 1983/84



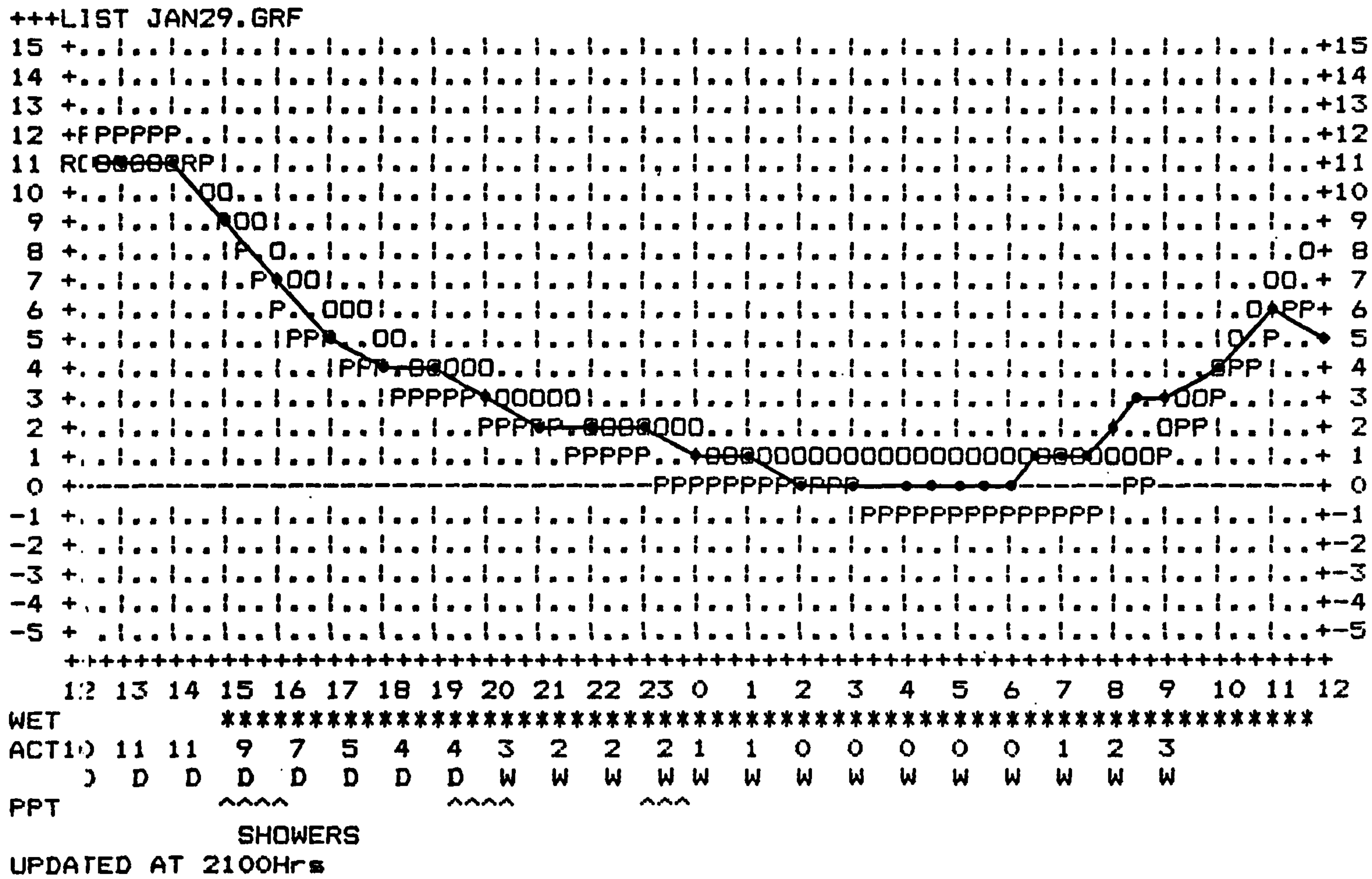


FIGURE 8.2 Forecast versus actual road surface temperatures for M5/M6 interchange for the night of 29th January 1984. As issued to West Midlands County Council

shown in Figure 8.3 as history pages which can also be accessed by West Midlands.

8.3 Data Processing and the Production of the Road Danger Warning

Figure 8.2 shows that two forecast road surface temperature curves are produced, the one represented by an "O" is an optimistic forecast, and the "P" represents a pessimistic forecast. Where the two coincide an "R" is printed. Obviously a 24 hour forecast can rarely be accurate and hence the concept of two forecasts. The optimistic forecast is produced assuming that all the forecast input data combines to raise the forecast road surface temperature, and the pessimistic forecast the reverse. Hence the amount of separation between the two curves represents the uncertainty of the meteorological situation. If both curves remain above the 0°C line then the maintenance engineer can assume that there is no problem, and send all his maintenance crews home. If both curves are below the 0°C line then the engineer must pay attention to the wetness of the road, and the precipitation forecast given below the graph. If ice or frost or snow are likely then the roads must be salted unless there is already sufficient salt down to cope with the situation. In this case the precipitation forecast is the most important, rather than the forecast road surface temperature.

If the optimistic curve is above the 0°C line and the pessimistic is below, then a standby situation exists in which the forecast will be updated at regular intervals. The maintenance engineer requires at least three hours warning of icy conditions, and hence the model must be run at regular intervals to make sure that the actual observed temperatures fit the prediction.

FIGURE 8.3 An example history page for sensor 4 at Ray Hall for the night of January 29th/30th 1984

University of Birmingham — Time 07:04 30 January 1984

Power on at: 16:09 on 21/12/83

Sensor # 4 — History page — M5/M6 Slow Lane

Time	Day	Status	Rel. Hum.	Freeze Factor		Temperatures Surf.		Air	Dew pt.	Wind Dir/Vel
07:03	30	Moisture	82	05	*	1.1	*	2.2	-1.1	226/ 9
06:35	30	Moisture	82	05	*	1.1	*	2.7	-0.5	234/ 9
06:03	30	Moisture	81	05	*	0.5	*	2.7	-0.5	241/ 5
05:35	30	Moisture	81	05	*	0.5	*	2.7	-0.5	259/ 10
05:04	30	Moisture	81	05	*	0.5	*	2.7	-0.5	266/ 6
04:34	30	Moisture	81	35	*	0.5	*	2.7	-0.5	262/ 7
04:03	30	Moisture	81	65	*	0.5	*	2.7	-0.5	262/ 8
03:04	30	Moisture	80	85	*	0.5	*	3.3	0.0	273/ 9
02:03	30	Moisture	79	85	*	0.5	*	3.3	-0.5	266/ 9
01:03	30	Moisture	80	85	*	1.1	*	2.7	-0.5	252/ 12
00:03	30	Moisture	80	85	*	1.1	*	2.7	-0.5	252/ 12
23:03	29	Moisture	81	85	*	1.6	*	2.7	-0.5	237/ 11
22:03	29	Moisture	80	85	*	2.2	*	3.3	0.0	244/ 10
21:04	29	Moisture	80	85	*	2.2	*	3.3	0.0	241/ 7
21:03	29	Moisture	80	85	*	2.2	*	3.3	0.0	244/ 5

At present the model is run first of all between noon and 1300 to give a full 24 hour forecast. The actually observed road surface temperature, air temperature, humidity, wind speed, cloud amount and type at noon is fed into the model along with forecast values for 1500 hrs, 1800 hrs, 2400 hrs, 0600 hrs, and 1200 hrs the following day. The model is run twice using optimistic and pessimistic forecasts. The cloud forecasts are provided by Elmdon Meteorological Office, but all the other forecasts are produced by the Meteorological Services Unit at Birmingham University. The duty maintenance engineer from West Midlands (Mr. Snow!) accesses the graph at about 1500 hrs. If an update is expected on the forecasts this is stated on the bottom of the graph. The Meteorological Services Unit closes at 2100 hrs, and hence any updateis usually run between 1900 hrs and 2100 hrs. As stated above an update is issued if the two forecasts fall either side of the 0°C line, but also if the actually observed temperatures are seen to diverge outside the range of the forecast temperatures.

8.4 Dissemination of the Graphical Road Danger Warnings

The maintenance engineer can access the forecast graph using a portable printer terminal connected via an acoustic coupler to an ordinary telephone. This is a very convenient arrangement providing that the portable terminal is easily portable, and that the acoustic coupler works properly. The maintenance engineer can use the same terminal at home, as in the office, and a printout is obtained which can be filed away once the actual temperatures have been plotted upon it. Also the terminal can be used to dial the site at Ray Hall to get up-to-date information to plot on the graph, and also a history page is available of the last 15 sets of observations (as shown in Figure 8.3). A full discussion of the results for the 1983/84 winter is given in Thornes (1984a) and Thornes (1984b).

8.5 Future Developments of this System

This graphical form of the Road Danger Warnings appears to be a considerable improvement on present Road Danger Warnings. However if this type of Road Danger Warnings is to be introduced nationwide there are many repercussions for the manning of weather centres to be considered. The stucture of an ideal system is shown in Figure 8.4. Each weather centre would be the hub of several networks of road sensors around a region. Data from these sensors would be processed automatically to produce road surface temperature forecasts for each site. These forecasts would then be disseminated to the maintenance engineers via Prestel. For each site there would be allocated a number of Prestel pages that would display the actual road surface conditions, the history of the previous 24 hour data, and the forecast for the present day and night. Maintenance engineers would then be able to receive the data either in the office or at home in colour. There would be no problem with acoustic couplers and the engineers would also send messages to the forecaster about details of salting, or for more information. In the next few years colour radar and meteosat pictures could also be obtained on Prestel, although it is unlikely that the maintenance engineers will require such detailed information. They would prefer the radar and meteosat information to be interpreted by the forecaster and fed into the graphical Road Danger Warnings.

The one major drawback to this scheme is the assumption that the local weather centres are capable, or indeed want to take part in such reorganisation. At present local weather centres do not use micro-computers, and yet the proposed system envisages the use of micro-

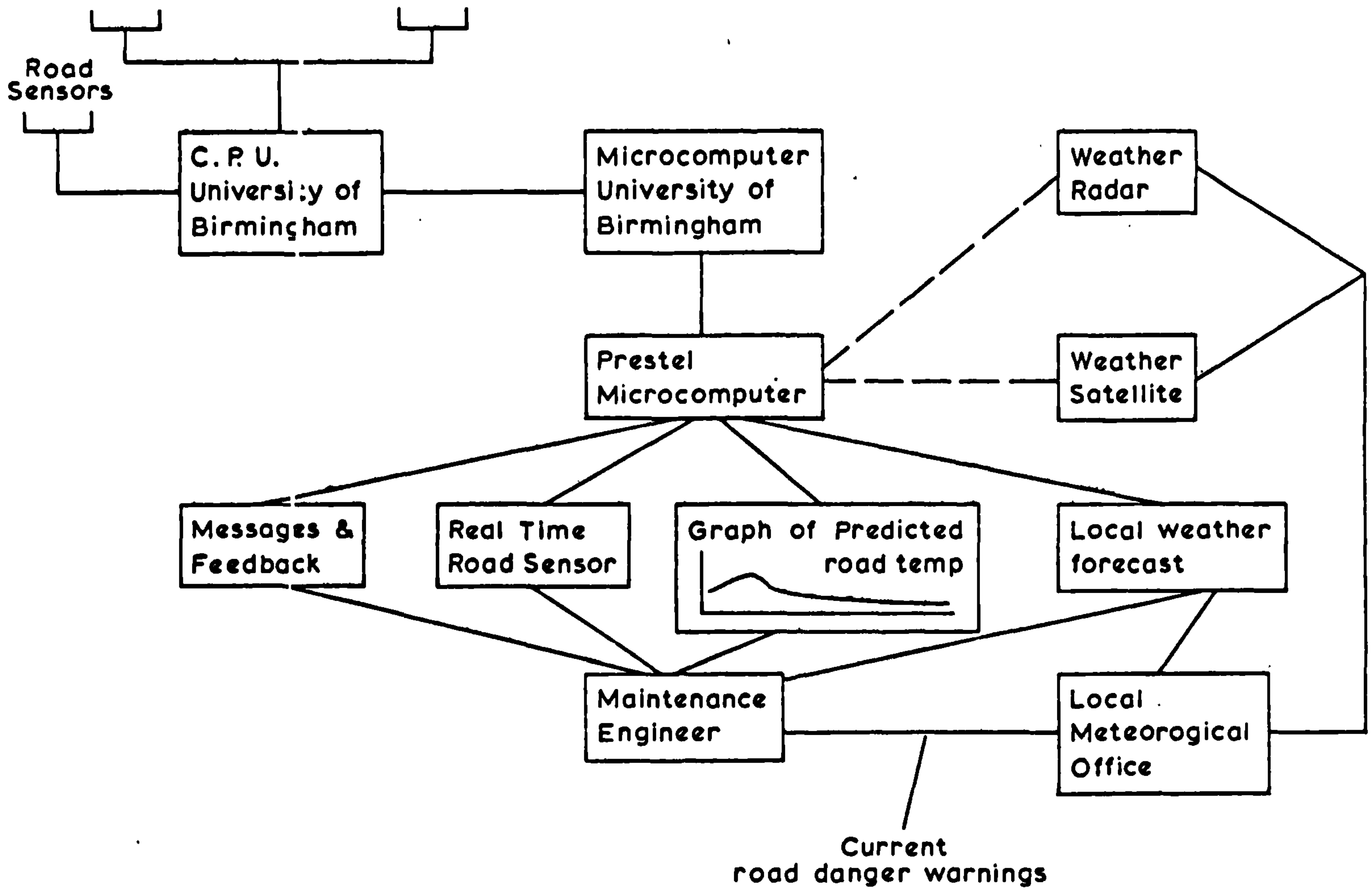


FIGURE 8.4

Proposed System of information flow to improve Road Danger Warnings computers, or perhaps even minicomputers to handle forecasts for perhaps a dozen sensor sites. For a 24 hour shift this would require the retraining or hiring of at least six meteorologists, with computing experience, per weather centre. Obviously this would have to be paid for out of the income from Road Danger Warnings. There would have to be a total reorganisation of the present system.

Already moves have been made in this direction, and a steering committee has been set up by the Department of Transport to look at the cost/benefit of such a scheme. A series of recommendations to introduce a trial at Elmdon for the winter of 1984/85 are currently being considered as shown in Table 8.1.

A similar steering committee set up in Finland produced its final report in 1982 (Finnish Road Weather 1982). The report recommends that Finland be split into three geographical areas with different levels of service in each. A comprehensive 24 hour service is to be provided in the Helsinki - Turku region in the south which will be equivalent to an automatic Prestel system as decribed above. In the other two regions a less comprehensive system will be implemented, mainly because they are much less densely populated. The report concludes:

'The annual expenses incurred by the final system would be 2.6 - 2.8 million FIM. In comparing (this sum) with the road maintenance savings (6.9 - 7.4 million FIM), it can be stated that the road weather service is a highly profitable activity and that the cost to benefit ratio follows the main trends ....1:3.'

Table 8.1

Recommendations Submitted to the Standing Committee on Highway Maintenance (SCHM) Department of Transport

1. We believe that ice prediction systems should not be specified separately for trunk and local roads. It is therefore essential that the Department and Agent Authorities collaborate in the specification and installation of area wide systems.

2. It appears reasonable that the cost of installation be divided between the Department and Agent Authorities on the basis of agreed relative costs of salting trunk and local roads.

3. We consider that ice prediction systems cannot be effectively deployed without the active participation of the Meteorological Office, to provide meteorological expertise and a forecasting service based on the research done at the University of Birmingham.

4. We recommend that the Meteorological Office be invited to take part in pilot application exercises this winter in West Midlands and in Hereford and Worcester. In each of these areas sensors should be installed in the road to measure surface temperature, road wetness and salinity, and atmospheric sensors installed to measure air temperature. At two key sites in each area, additional instruments should be provided to measure temperature at depth in the road structure, relative humidity, wind speed and wind direction. The total cost of installing and operating these systems is likely to be £227,400.

5. We recommend that a Steering Group be formed to monitor these pilot application exercises on behalf of the Winter Maintenance Committee. The Steering Group should comprise representatives of the Department, the County Surveyors Society, the Meteorological Office and participating local authorities. Experience gathered in the pilot application studies should form a basis upon which to secure wider application of ice prediction systems in subsequent years. It is hoped that the Meteorological Office will consider the need to plan for this wider application.

6. Ice prediction equipment should conform to defined standards of safety and performance, particularly with regard to installation and communications. The assistance of the Traffic Control and Communication Division of the Department and the special Advisory Group for ice prediction of the County Surveyors Society should be sought to provide the necessary type approval of equipment and monitoring of installations.

7. Should the system be more widely applied in subsequent years then advance thermal mapping would be necessary and should be encouraged.

Hence the Finns have decided to set up a regional network for winter maintenance. In Britain our population is more evenly spread and therefore it is more likely that the same level of service will be required throughout the country. Perhaps Northern Scotland or Mid-Wales might have less need for a 24 hour service. These are issues yet to be discussed.

Finally it is important to reiterate that if a national system of some sort is not set up then each country and local authority will continue to go its own way, and the winter maintenance practices will vary throughout the country. The Meteorological Office already has a regional network of weather centres that provide the current Road Danger Warnings. They must be persuaded by the County Councils and the Department of Transport that it is in the Meteorological Offices's interest to bring up-to-date their Road Danger Warning service. The Department of Transport can afford to pay for the installation of sensors if the Meteorological Office is prepared to retrain their staff to handle the data. At a time when mesoscale forecasting is receiving more attention in weather forecasting circles the additional information provided by remote sensors will be invaluable.

8.6 Final Comments

This thesis attempts to cut across the traditional boundaries of meteorology and municipal engineering. In doing so many assumptions have had to be made to realise a final useable model for the production of more accurate Road Danger Warnings. Research does not stop here however. Although the model has and is performing remarkably well considering its primitive physical base, more research is required to narrow the gap between optimistic and pessimistic forecasts. Also thermal maps of all main roads are required to ascertain the micro-climatic differences in road surface temperature around the region. Road Danger Warnings issued by the Meteorological Office have hardly altered in format in 30 years. It is time for change.

CHAPTER 9 CONCLUSION

9.1. Introduction

The data used in this thesis to test the road surface temperature prediction model, has been collected over a period of five years from 1979 to 1984. During this time the model has evolved and been adapted to produce an output suitable for use by a practicing maintenance engineer. The results have been encouraging to the extent that the model is now to be used by the Meteorological Office for producing Road Danger Warnings at Elmdon Weather Centre, starting with the winter of 1984/85. The recommendations outlined in Table 8.1 have been fully approved by the Department of Transport and the Meteorological Office. The equipment used at Birmingham University to test the model in real time, will be transferred to Elmdon Weather Centre during the Autumn of 1984. Birmingham University will stay involved in the project, acting as consultants to the Meteorological Office, and also running a company entitled 'Thermal Mapping International' which will start to 'thermally map' the roads of Britain and Europe. During September 1984 the University is host to the 'International Road Weather Conference' which will bring together the latest developments in winter maintenance practices. It can be summised from these statements that the research is still ongoing. Nevertheless sufficient has already been learned to significantly improve Road Danger Warnings in Britain and also with the aid of thermal mapping it is possible to give more accurate regional Road Danger Warnings.

9.2 Fulfilment of The Aims of the Thesis

The road surface temperature prediction model developed, tuned, tested and reported in this thesis represents a useful framework for future developments of Road Danger Warnings. The model can still be improved to provide more accurate optimistic and pessimistic forecasts. More development is required to disseminate the forecast information to maintenance engineers over a medium such as Prestel. A faster micro-computer is needed to enable the model to be run quickly for many sites at once.

The gap between research and operational use has yet to be finally closed. County Councils are spending a great deal of money to put sensors into their roads. Golland (1984) the Principal Engineer for Maintenance Management for West Midlands County Council states:

> 'The installation of an ice early warning system is fairly expensive and has, to some extent been an act of faith by the few Highway Authorities who have taken the plunge. However, evidence is accumulating which would suggest that the investment is economically justifiable due to the potential savings which are available once the operational users establish their faith in it and develop experience in using it effectively.
>
> The maximum potential at present lies in improving the accuracy of forecasts, which can only be achieved by reducing the area covered by one forecast. The computer model developed by the Meteorology Department of Birmingham University on behalf of the TRRL has proved to be a very promising development, and there would be considerable benefits available to all Highway Authorities with ice warning systems if the model could be extended in operation.'

The aims of this thesis set out in Chapter One, have been largely fulfilled. The success of the model will now depend upon the Meteorological Office, and the speed with which they can gear up to the use of micro-computers in regional weather centres.

9.3 Summary of Conclusions

This thesis has shown that the meteorological dimension of winter maintenance in Britain has been largely ignored. In order to fill this gap the following findings of this thesis are presented:-

(1) Current Road Danger Warnings issued to Highway Authorities are inadequate.

(2) An extensively modified version of the heat balance model proposed by Outcalt (1971) can be used successfully to predict road surface temperatures up to 24 hours ahead, despite it s primitive physical base.

(3) The form of the Road Danger Warning needs to be changed. A graphical presentation, with 'optimistic' and 'pessimistic' scenarios is presented. This form seems to be prefered by maintenance engineers.

(4) Sensors embedded in the road surface are necessary to measure road surface temperature, wetness and salinity. This information can then be fed directly into the heat balance model, and used to check the model's performance in real time.

(5) Thermal mapping is needed to locate the sensors in their optimum location, and to provide an accurate 'fingerprint' of road surface temperatures between sensors.

(6) A national network of sensors is required to feed into the local weather centres around Britain. This is already under discussion with the Meteorological Office, and a trial is being mounted at Elmdon airport for the winter of 1984/85.

(7) Expenditure on winter maintenance can potentially be reduced by up to 50%; a considerable saving on the current annual budget of up to £120 million in Britain.

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APPENDIX 1

The Fortran Model

```
0001            DIMENSION SOL(72),SHD(72),BEAM(72),EXT(72),DIFF(72),
               1BACSKT(72),SLAB(72),SHOW(72),TE(72),T35(72),TIME(72),
               1SUN(72),T(72),RN(72),S(72),H(72),LE(72),T17(72),UA(72),
               1EXCO(72),ZA(72),EXXO(72),TT(72),TC(72),TZ(72),TX(72),TU(72)
               1,ALBEDO(72),RI(72),TA(72),V(72),W(72),T3(72),T18(72),T9(72)
               1,T5(72),SUM(72),YSHMB(72),RHF(72),AT(72),IA(4),
               1X(4),Y(4),Z(4),ALBED(4),DPLUS(4),KCLOU(4),TD(72)
               1,Y1(72),XX(72),YY(72),IT(4),AIR(72),T36(72),TITLE(20)
0002            INTEGER TITLE
0003            REAL KARMAN,LE,KCLOU1,KCLOU
0004            BYTE PROMPT(72)
0005            DOUBLE PRECISION DNC
0006            ZTK(TC)=TC+273.16
0007            ZTC(TK)=TK-273.16
0008            BB(TK)=(8.14E-8)*(TK*TK*TK*TK)
0009      5     CALL ASN('INPUT FILE',1)
0010            CALL ASN('OUTPUT FILE',-2)
          C
          C     PHYSICAL CONSTANTS
          C
0011            KARMAN=.4
0012            LHEAT=590.0
0013            LHSUB=677.
0014            DRYADB=1.E-4
0015            AIRCAP=.24
0016            D=0.5
0017            AIRDEN=1.E-3
0018            XLAT=51.
0019            RDA=6.94E-3
0020            RDC=1.2E-2
0021            RKA=3.1E-3
0022            RKC=4.8E-3
0023            Z0=15.0
0024            ZG=72.
0025            SHDRAT=.0
          C
          C     READ IN DATE
          C
0026     10     CALL TNOUA('$WHAT IS THE DAY OF THE MONTH:',30)
0027            READ(5,11)JDAY
0028            CALL TNOUA('$WHAT IS THE MONTH:',19)
0029            READ(5,11)JMON
0030            CALL TNOUA('$WHAT IS THE YEAR:',18)
0031            READ(5,11)JYEAR
0032            IF(JDAY.LE.0.OR.JDAY.GT.31.OR.JMON.GT.12)STOP
0033            IF(JYEAR.LT.1950)STOP
0034            TOY=JDAY
0035            IF(JMON.EQ.2) TOY=31+JDAY
0036            IF(JMON.EQ.3) TOY=59+JDAY
```

```
            IF(JMON.EQ.4) TOY=90+JDAY
            IF(JMON.EQ.5) TOY=120+JDAY
            IF(JMON.EQ.6) TOY=151+JDAY
            IF(JMON.EQ.7) TOY=181+JDAY
            IF(JMON.EQ.8) TOY=212+JDAY
            IF(JMON.EQ.9) TOY=243+JDAY
            IF(JMON.EQ.10) TOY=273+JDAY
            IF(JMON.EQ.11) TOY=304+JDAY
            IF(JMON.EQ.12) TOY=334+JDAY
            IF(JMON.GE.3.AND.MOD(JYEAR,4).EQ.0)TOY=TOY+1
            LEAP=12
            DO 20 IYEAR=1950,JYEAR-1
            IF(MOD(IYEAR,4).EQ.0)LEAP=LEAP+1
   20       CONTINUE
            DAYS=(JYEAR-1900)*365+LEAP+TOY-0.5
            WRITE(2,21)JDAY,JMON,JYEAR
            WRITE(5,21)JDAY,JMON,JYEAR
C
C           METEOROLOGICAL INPUT VALUES READ IN
C
            CALL TNOUA('$ROAD SURFACE TEMP AT 1200HRS:',30)
            READ(5,31)SURF
            CALL TNOUA('$ROAD TEMP. AT 72CM,36CM AND 18CM:',34)
            READ(5,41)TH,TT(1),TZ(1)
            CALL TNOUA('$FORECAST AVERAGE WIND 12-24,24-12 IN CM/S:',43)
            READ(5,46)UA(1),UA(37)
            CALL TNOUA('$TIME ROAD EXPECTED WET:',24)
            READ(5,11)MWET
            IF(MWET.EQ.0) GOTO 60
            CALL TNOUA('$RAIN HEAVY(-1),MEDIUM(0),LIGHT(1)? :',37)
            READ(5,11)M
            IF(M)30,40,50
   30       RAIN=-3000.0
            GOTO 60
   40       RAIN=-1500.0
            GOTO 60
   50       RAIN=-500.0
   60       IF(MWET.EQ.0)SRHF=0.0
            SRHF=0.0
            IF(MWET.GE.1.AND.MWET.LT.12)LWET1=37+MWET*3
            IF(MWET.GE.12.AND.MWET.LE.24)LWET1=1+3*(MWET-12)
            IF(MWET.GT.24)STOP
            CALL TNOUA('$AIR TEMP. FORECAST FOR 1200HRS:',32)
            READ(5,31)TA1
            CALL TNOUA('$RELATIVE HUMIDITY FRAC. FOR 1200HRS:',37)
            READ(5,31)RF1
            CALL TNOUA('$AIR TEMP. FORECAST FOR 1500HRS:',32)
            READ(5,31)TA2
            CALL TNOUA('$RELATIVE HUMIDITY FRAC. FOR 1500HRS:',37)
            READ(5,31)RF2
```

```
      CALL TNOUA('$AIR TEMP. FORECAST FOR 1800HRS:',32)
      READ(5,31)TA3
      CALL TNOUA('$RELATIVE HUMIDITY FRAC. FOR 1800HRS:',37)
      READ(5,31)RF3
      CALL TNOUA('$AIR TEMP. FORECAST FOR 2400HRS:',32)
      READ(5,31)TA4
      CALL TNOUA('$RELATIVE HUMIDITY FRAC. FOR 2400HRS:',37)
      READ(5,31)RF4
      CALL TNOUA('$AIR TEMP. FORECAST FOR 0600HRS:',32)
      READ(5,31)TA5
      CALL TNOUA('$RELATIVE HUMIDITY FRAC. FOR 0600HRS:',37)
      READ(5,31)RF5
      DO 120 J=1,4
      CALL TNOUA('$CLOUD AMOUNT:',14)
      READ(5,11)IA(J)
      CALL TNOUA('$CLOUD TYPE:',12)
      READ(5,16)IT(J)
      IF(IA(J).GE.1.AND.IA(J).LE.7) GOTO 70
      IF(IA(J).NE.0) GOTO 65
      X(J)=0.0
      Y(J)=0.5
      Z(J)=1.0
      GOTO 110
65    X(J)=1.0
      Y(J)=1.0
      Z(J)=0.78
      IF(IT(J).EQ.'L')Z(J)=0.32
      IF(IT(J).EQ.'M')Z(J)=0.54
      GOTO 110
70    IF(IT(J).EQ.'L')GOTO 80
      IF(IT(J).EQ.'M')GOTO 90
      GOTO 100
80    X(J)=0.2
      Y(J)=0.6
      Z(J)=0.87
      IF(IA(J).GE.1.AND.IA(J).LE.2) GOTO 110
      X(J)=0.5
      Y(J)=0.8
      Z(J)=0.58
      IF(IA(J).GE.3.AND.IA(J).LE.5) GOTO 110
      X(J)=0.9
      Y(J)=1.0
      Z(J)=0.32
      GOTO 110
90    X(J)=0.1
      Y(J)=0.6
      Z(J)=0.91
      IF(IA(J).GE.1.AND.IA(J).LE.2) GOTO 110
      X(J)=0.3
      Y(J)=0.8
```

```
            Z(J)=0.72
            IF(IA(J).GE.3.AND.IA(J).LE.5) GOTO 110
            X(J)=0.9
            Y(J)=1.3
            Z(J)=0.54
            GOTO 110
      100   X(J)=0.05
            Y(J)=0.5
            Z(J)=0.96
            IF(IA(J).GE.1.AND.IA(J).LE.2) GOTO 110
            X(J)=0.1
            Y(J)=0.5
            Z(J)=0.86
            IF(IA(J).GE.3.AND.IA(J).LE.5) GOTO 110
            X(J)=0.3
            Y(J)=0.6
            Z(J)=0.78
      110   CONTINUE
            IF(IA(J).GT.8.OR.IA(J).LT.0)STOP
            ALBED(J)=X(J)
            DPLUS(J)=Y(J)
            KCLOU(J)=Z(J)
      120   CONTINUE
C
C           WRITE OUT BOUNDARY CONDITIONS
C
            WRITE(2,51)
            WRITE(5,51)
            WRITE(2,61)
            WRITE(5,61)
            WRITE(2,71)TA1,TA2,TA3,TA4,TA5
            WRITE(5,71)TA1,TA2,TA3,TA4,TA5
            WRITE(2,81)
            WRITE(5,81)
            WRITE(2,91)RF1,RF2,RF3,RF4,RF5
            WRITE(5,91)RF1,RF2,RF3,RF4,RF5
            WRITE(2,101)
            WRITE(5,101)
            WRITE(2,111)
            WRITE(5,111)
            WRITE(2,121)
            WRITE(5,121)
            DO 130 J=1,4
            WRITE(2,131) IA(J),IT(J)
            WRITE(5,131) IA(J),IT(J)
      130   CONTINUE
            WRITE(2,141)
            WRITE(5,141)
            WRITE(2,151)X(1),X(2),X(3),X(4)
            WRITE(5,151)X(1),X(2),X(3),X(4)
```

```
      WRITE(2,161)
      WRITE(5,161)
      WRITE(2,171)Y(1),Y(2),Y(3),Y(4)
      WRITE(5,171)Y(1),Y(2),Y(3),Y(4)
      WRITE(2,181)
      WRITE(5,181)
      WRITE(2,191)Z(1),Z(2),Z(3),Z(4)
      WRITE(5,191)Z(1),Z(2),Z(3),Z(4)
C
C     CONVERT TEMPS TO KELVIN SCALE
C
      TT(1)=ZTK(TT(1))
      TZ(1)=ZTK(TZ(1))
      TH=ZTK(TH)
      DO 160 I=1,72
      TA(I)=TA1
      RHF(I)=RF1
      IF(I.GE.1.AND.I.LE.9)GOTO 135
      TA(I)=TA2
      RHF(I)=RF2
      IF(I.GT.9.AND.I.LE.18) GOTO 135
      TA(I)=TA3
      RHF(I)=RF3
      IF(I.GT.18.AND.I.LE.36) GOTO 135
      TA(I)=TA4
      RHF(I)=RF4
      IF(I.GT.36.AND.I.LE.54) GOTO 135
      TA(I)=TA5
      RHF(I)=RF5
  135 IF(I.GT.36)UA(I)=UA(37)
      IF(I.GT.36) GOTO 138
      UA(I)=UA(1)
  138 IF(TA(I).LT.-10.0.OR.TA(I).GT.30.0)GOTO 350
      TA(I)=ZTK(TA(I))
      YSHMB(I)=SHMB(TA(I))
      V(I)=RHF(I)*YSHMB(I)
      W(I)=1.5*V(I)+0.6
      IF(I.GT.1)GOTO 140
      WRITE(5,201)
      WRITE(2,201)
      WRITE(5,211)YSHMB(1),V(1),RHF(1),W(1)
      WRITE(2,211)YSHMB(1),V(1),RHF(1),W(1)
  140 CONTINUE
      IF(I.NE.1.AND.I.NE.37) GOTO 150
      ZA(I)=ZAIR(UA(I),ZO)
      EXCO(I)=((KARMAN**2)*AIRDEN*UA(I))/((ALOG(ZA(I)/ZO))**2)
      GOTO 160
  150 ZA(I)=ZA(1)
      EXCO(I)=EXCO(1)
      IF(I.LT.37) GOTO 160
```

```
            ZA(I)=ZA(37)
            EXCO(I)=EXCO(37)
  160       CONTINUE
C
C           WRITE DAMPING DEPTHS
C
            WRITE(2,221)ZG,ZA(1),ZA(37),EXCO(1),EXCO(37)
            WRITE(5,221)ZG,ZA(1),ZA(37),EXCO(1),EXCO(37)
C
C           GENERATE AND WRITE RADIATION
C
            DO 180 I=1,72
            ALBED1=ALBED(1)
            DPLUS1=DPLUS(1)
            IF(I.LE.18)GOTO 165
            ALBED1=ALBED(2)
            DPLUS1=DPLUS(2)
            IF(I.LE.36) GOTO 165
            ALBED1=ALBED(3)
            DPLUS1=DPLUS(3)
            IF(I.LE.54) GOTO 165
            ALBED1=ALBED(4)
            DPLUS1=DPLUS(4)
  165       J=MOD(I+36,72)
            IF(J.EQ.0)J=72
            TIME(I)=(J-1)/3
            IF(MOD(I-1,3).NE.0) GOTO 170
            MIN=I-1
            CALL SUNDEC(DAYS,TIME(1),MIN,DEC,R)
  170       CONTINUE
            CALL SUNGEN(DEC,W(I),D,R,J,EXT(I),BEAM(I),DIFF(I),
         1BACSKT(I),SOL(I),SHD(I),ALBEDO(I),ALBED1,ALBED2,ALBED3,
         1ALBED4,DPLUS1,DPLUS2,DPLUS3,DPLUS4)
            SUN(I)=(1.-SHDRAT)*SOL(I)+SHDRAT*SHD(I)
  180       CONTINUE
            WRITE(2,231)
            WRITE(5,231)
            WRITE(2,241)DEC,R,TT(1),TZ(1),SURF,UA(1),UA(37),D,MWET
            WRITE(5,241)DEC,R,TT(1),TZ(1),SURF,UA(1),UA(37),D,MWET
            WRITE(2,251)
C           WRITE(5,251)
C
C           INTERVAL HALVING ALGORITHM
C
            DO 310 I=1,72
            SUM(1)=0.0
            K=1
            Z1=TA(I)-20.0
            Z2=TA(I)+20.0
            SHOW(1)=0.0
```

```
      GOTO 210
  190 T(I)=Z2
      GOTO 220
  200 K=K+1
      IF(K.EQ.2) GOTO 190
      T(I)=TE(K-1)-((TE(K-1)-TE(K-2))*SHOW(K-1))/(SHOW(K-1)-SHOW(K-2))
      GOTO 220
  210 T(I)=Z1
  220 KCLOU1=KCLOU(1)
      TE(K)=T(I)
      IF(I.GT.18)KCLOU1=KCLOU(2)
      IF(I.GT.36)KCLOU1=KCLOU(3)
      IF(I.GT.54)KCLOU1=KCLOU(4)
      RNLONG=(0.95*(BB(T(I))))-((BB(TA(I)))*(0.82-0.25*(10.0**(-0.094
     1*V(I)))))
      RN(I)=(1.-ALBEDO(I))*SUN(I)-RNLONG*KCLOU1
C
C     INTRODUCE LAG
C
      IF(I.GT.1) GOTO 230
      TX(I)=(TZ(I)+T(I))/2.0
      TU(I)=(TX(I)+T(I))/2.0
      ZT=ZG/2.0
      ZZ=ZT/2.0
      ZX=ZZ/2.0
      ZU=ZX/2.0
      GOTO 240
  230 TT(I)=TT(I-1)+RDC*((T(I-1)-2.*TT(I-1)+TH)/(ZT*ZT))*1.2E3
      TZ(I)=TZ(I-1)+RDC*((T(I-1)-2.*TZ(I-1)+TT(I-1))/(ZZ*ZZ))*1.2E3
      TX(I)=TX(I-1)+RDA*((T(I-1)-2.*TX(I-1)+TZ(I-1))/(ZX*ZX))*1.2E3
      TU(I)=TU(I-1)+RDA*((T(I-1)-2.*TU(I-1)+TX(I-1))/(ZU*ZU))*1.2E3
  240 S(I)=(RKA/ZU)*(TU(I)-T(I))*60.E3
      IF(I.EQ.LWET1)SRHF=1.0
      EXXO(I)=EXCO(I)*RIFIX(TA(I),T(I),ZA(I),ZO,UA(I),RI(I))
      H(I)=EXXO(I)*AIRCAP*(TA(I)+DRYADB*ZA(I)-T(I))*60.E3
      QGRAD=Q(TA(I),RHF(I))-Q(T(I),1.00)
      IF(QGRAD.GT.0.0)  GOTO   270
      LE(I)=EXXO(I)*LHEAT*QGRAD*60.E3*SRHF
      GOTO 280
C
C     DEW FALLS EVERYWHERE
C
  270 LE(I)=EXXO(I)*LHEAT*QGRAD*60.E3
  280 CONTINUE
      SHOW(K)=RN(I)+S(I)+H(I)+LE(I)
      IF(SHOW(K).GT.1.OR.SHOW(K).LT.-1.0) GOTO 200
      IF(I.EQ.1)GOTO 290
      SUM(I)=SUM(I-1)+LE(I)
  290 IF(SUM(I).LT.RAIN)SRHF=0.0
C
```

```
C         CONVERT SURF.TEMP. TO CELCIUS
C
          TC(I)=ZTC(T(I))
          T18(I)=ZTC(TZ(I))
          T9(I)=ZTC(TX(I))
          T5(I)=ZTC(TU(I))
          T35(I)=ZTC(TT(I))
          TD(1)=SURF
          IF(I.EQ.1) GOTO 300
          TD(I)=TC(I)+(TD(I-1)-TC(I))/2.0
  300     WRITE(2,261)TIME(I),SUN(I),RN(I),S(I),H(I),LE(I),TD(I),
       1TC(I),SUM(I),RI(I)
  310     CONTINUE
          WRITE(5,251)
          DO 320 I=1,72
  320     WRITE(5,261)TIME(I),SUN(I),RN(I),S(I),H(I),LE(I),TD(I),
       1TC(I),SUM(I),RI(I)
          DO 330 JP=1,24
          I=-1+3*JP
          TIME(I)=TIME(I)+0.3
  330     CONTINUE
          DO 340 JR=1,24
          I=3*JR
          TIME(I)=TIME(I)+0.6
  340     CONTINUE
C
C         GRAPHICS
C
          GOTO 370
  350     CONTINUE
          WRITE(2,271)
          WRITE(5,271)
  360     CONTINUE
  370     CONTINUE
C
C         FORMAT STATEMENTS
C
   11     FORMAT(I)
   16     FORMAT(A)
   21     FORMAT(1X,4HDAY:,I2,5X,6HMONTH:,I2,5X,5HYEAR:,I4/)
   31     FORMAT(F)
   41     FORMAT(3F)
   46     FORMAT(2F)
   51     FORMAT(10X.'****INPUT DATA****')
   61     FORMAT(5X,'TA1',5X,'TA2',5X,'TA3',5X,'TA4',5X,'TA5')
   71     FORMAT(5(4X,F4.1))
   81     FORMAT(5X,'RF1',5X,'RF2',5X,'RF3',5X,'RF4',5X,'RF5')
   91     FORMAT(5(4X,F4.2))
  101     FORMAT(' CLOUD CONDITIONS FOR  1200  1800  0000 0600')
  111     FORMAT(' CLOUD AMOUNT          CLOUD TYPE')
```

```
121     FORMAT(' IN OCTAS')
131     FORMAT(5X,I1,20X,A4)
141     FORMAT(' ALBED1      ALBED2      ALBED3      ALBED4')
151     FORMAT(1X,F5.2,5X,F5.2,8X,F5.2,5X,F5.2)
161     FORMAT(' DPLUS1      DPLUS2      DPLUS3      DPLUS4')
171     FORMAT(1X,F5.2,5X,F5.2,8X,F5.2,5X,F5.2)
181     FORMAT(' KCLOU1      KCLOU2      KCLOU3      KCLOU4')
191     FORMAT(1X,F5.2,5X,F5.2,8X,F5.2,5X,F5.2)
201     FORMAT(10X,'***COMPUTED DATA***')
211     FORMAT(10X,'SAT. VAP. PRESSURE(MB)=',F6.2,/,10X,
       1'VAPOUR PRESSURE(MB)=',F6.2,/,10X,'REL. HUMIDITY FRACTION=',
       1F6.2,/,10X,'APPROX. PRECIP. WATER(MM)=',F6.1)
221     FORMAT(10X,'ROAD DAMPING DEPTH(CM)=',F8.0,/,10X,
       1'AIR DAMPING DEPTH(CM)=',2F10.0,/,10X,
       1'AIR HEAT TRANSFER COEF.(CGS)=',2F10.5)
231     FORMAT(3X,'DEC',7X,'R',4X,'T36',2X,'T18',3X,'TS',5X,
       1'UA',7X,'D',7X,'TIME WET')
241     FORMAT(2F8.3,2F5.1,F6.1,2F5.0,F6.1,6X,I4)
251     FORMAT(1X,'SOLAR',2X,'SUN',3X,'RN',4X,'S',5X,'H'
       1,5X,'LE',6X,'TD',5X,'TC',5X,'SUM',6X,'RI',/,'TIME',
       114X,'(ALL MLY./MIN.)',12X,'(C.)')
261     FORMAT(1X,F5.1,1X,F5.1,1X,F6.1,3(1X,F5.0),2X,F6.2
       1,1X,F6.2,1X,F6.0,2X,F8.5)
267     FORMAT('$DO YOU WANT ANOTHER FORECAST?')
271     FORMAT(4X,'ERROR IN DATA --- CHECK ALL INPUT DATA')
        STOP
        END
```

```
      SUBROUTINE SUNGEN(DEC,W,D,R,I,EXT,BEAM,DIFF,BACSKT,SOL,
     1SHD,ALBEDO,ALBED1,ALBED2,ALBED3,ALBED4,DPLUS1,DPLUS2,
     1DPLUS3,DPLUS4)
      XLAT=51.
      SLIME=I-1
      HRAD=((SLIME*5.0)-180.0)/57.29578
      RLAT=XLAT/57.29578
      RDEC=DEC/57.29578
      COSZ=SIN(RLAT)*SIN(RDEC)+COS(RLAT)*COS(RDEC)*COS(HRAD)
      ALBEDO=0.1+0.131*(ACOS(COSZ)**4.0)
      XM=ABS(1./COSZ)
      ABSD=-0.174*(((W*XM)/20.)**0.6)
      SCAT=-0.083*((D*XM)**0.9)-0.089*((XM)**0.75)
      IF(COSZ.GT.0.) GOTO 100
      COSZ=0.0
  100 CONTINUE
      EXT=(2.E3/R**2)*COSZ
      BEAM=(1.-ALBED1)*EXT*EXP(ABSD+SCAT)
      DIFF=DPLUS1*EXT*(1.-EXP(SCAT))
      SOLAR=BEAM+DIFF
      BACSKT=0.5*ALBEDO*SOLAR*(1.-EXP(SCAT))
      SOL=SOLAR+BACSKT
      SHD=SOL+BEAM
      RETURN
      END
C
C
C
      FUNCTION RIFIX(TA,T,ZA,ZO,UA,RI)
      G=980.
      DRYADB=1.E-4
      TBAR=0.5*(TA+T)
      TGRAD=(TA+DRYADB*ZA-T)/ALOG(ZA/ZO)
      UGRAD=UA/ALOG(ZA/ZO)
      RI=(G/TBAR)*(TGRAD/(UGRAD**2.0))
      RIFIX=SQRT(SQRT(ABS(1.-18.0*RI)))
      RETURN
      END
C
C
C
      FUNCTION ZAIR(UA,ZO)
      ZA=ZO
      SNOW=2.E20
  100 ZA=ZA+1.0
      THEN=SNOW
      DOC=(.16*UA)/ALOG(ZA/ZO)
      DNC=(ZA*ZA)/5.184E5
      SNOW=ABS(DOC-DNC)
```

```
      IF(THEN.GT.SNOW)GOTO 100
      ZAIR=ZA
      RETURN
      END
C
C
C
      FUNCTION SHMB(TK)
      SATWTK=10.**(-7.90298*((373.16/TK)-1.)+5.02808*ALOG10(373.16/TK)
     1-1.3816E-7*(10.**(11.344*(1.-(TK/373.16)))-1.)
     2+8.1328E-3*(10.**(-3.49149*((373.16/TK)-1.))-1.)
     3+ALOG10(1013.246))
      SATITK=10.**(-9.09718*((273.16/TK)-1.)-3.56654*ALOG10(273.16/TK)
     1+0.876793*(1.-(TK/273.16))+ALOG10(6.1071))
      IF(TK.LT.273.16)GOTO 100
      SHMB=SATWTK
      GOTO 110
  100 CONTINUE
      SHMB=SATITK
  110 CONTINUE
      RETURN
      END
C
C
C
      FUNCTION Q(TK,RHF)
      Q=(0.622*SHMB(TK)*RHF)/1013.
      RETURN
      END
C
C
C
      FUNCTION ACOS(COSZ)
      SS=ABS(COSZ)
      IF(SS.GT.1.0) GOTO 100
      ACOS=(1.5707288+SS*(-0.2121144+SS*(0.074261-SS*0.0187293)))
     1*SQRT(1.0-SS)
      GOTO 110
  100 ACOS=0.0
  110 IF(COSZ.LT.0.0)ACOS=3.141572-ACOS
      RETURN
      END
C
C
C
      SUBROUTINE TNOUA(PROMPT,N)
      BYTE PROMPT(72)
      WRITE(5,10)(PROMPT(I),I=1,N)
   10 FORMAT(72A1,$)
      RETURN
```

```
      END
C
C
C
      SUBROUTINE SUNDEC(DAYS,HOUR,MIN,DEC,R)
      ANGRAD(DEG)=DEG/57.29578
      DEG(E)=E*57.29578
      D=DAYS+(HOUR+(MIN)/3.)/24.
      T=D/36525.
      SLONG=279.696678+0.9856473354*D+0.303E-3*T**2
      ANOMAL=358.475845+0.9856002670*D-0.150E-3*T**2
     1-0.3E-5*T**3
      E=0.01675104-0.4180E-4*T-0.126E-6*T**2
      EPSIL=23.452294-0.0130125*T-0.164E-5*T**2
     1+0.503E-6*T**3
      G=ANGRAD(ANOMAL)
      SLAM=SLONG+(2.0*DEG(E)-0.25*DEG(E**3))*SIN(G)
     1+1.25*DEG(E**2)*SIN(G*2.0)+13./12.*DEG(E**3)*SIN(G*3.0)
      RDEC=ASIN(SIN(ANGRAD(EPSIL))*SIN(ANGRAD(SLAM)))
      DEC=RDEC*57.29578
      R=1.0+0.5*E**2-(E-3./8.*E**3)*COS(G)-0.5*E**2*COS(G*2.0)
     1-3./8.*E**3*COS(G*3.0)
      RETURN
      END
```

Graphics program using GINO

```
CALL DEVSPE(2400)
CALL WINDOW(2)
CALL PENSEL(1,0.1,4)
CALL MOVTO2(20.0,240.0)
CALL CHAHOL(7HDATE:*.)
CALL MOVTO2(40.0,240.0)
CALL CHAA1(TITLE,20)
CALL MOVTO2(40.0,239.0)
CALL LINTO2(90.0,239.0)
CALL MOVTO2(25.0,230.0)
CALL CHAHOL(6HDEC:*.)
CALL MOVTO2(35.0,230.0)
CALL CHAFIX(DEC,6,2)
CALL MOVTO2(55.0,230.0)
CALL CHAHOL(4HR:*.)
CALL CHAFIX(R,5,3)
CALL MOVTO2(25.0,220.0)
CALL CHAHOL(32HBOUNDARY CONDITIONS:  UA1,UA2:*.)
CALL CHAFIX(UA(1),6,1)
CALL CHAFIX(UA(37),6,1)
CALL MOVTO2(140.0,220.0)
CALL CHAHOL(11HTIME WET:*.)
CALL CHAINT(MWET,3)
CALL MOVTO2(40.0,210.0)
CALL CHAHOL(46H1200       1500       1800       2400       0600*.)
CALL MOVTO2(20.0,200.0)
CALL CHAHOL(6HTO'C*.)
CALL MOVTO2(40.0,200.0)
CALL CHAFIX(SURF,4,1)
CALL MOVTO2(20.0,192.0)
CALL CHAHOL(7HT18'C*.)
CALL MOVTO2(40.0,192.0)
CALL CHAFIX(T18(1),4,1)
CALL MOVTO2(20.0,184.0)
CALL CHAHOL(7HT36'C*.)
CALL MOVTO2(40.0,184.0)
CALL CHAFIX(T35(1),4,1)
CALL MOVTO2(20.0,176.0)
CALL CHAHOL(6HTA'C*.)
CALL MOVTO2(40.0,176.0)
CALL CHAFIX(TA1,4,1)
CALL MOVTO2(67.0,176.0)
CALL CHAFIX(TA2,4,1)
CALL MOVTO2(93.0,176.0)
CALL CHAFIX(TA3,4,1)
CALL MOVTO2(119.0,176.0)
CALL CHAFIX(TA4,4,1)
CALL MOVTO2(145.0,176.0)
CALL CHAFIX(TA5,4,1)
CALL MOVTO2(20.0,168.0)
CALL CHAHOL(5HRHF*.)
CALL MOVTO2(40.0,168.0)
CALL CHAFIX(RF1,4,2)
CALL MOVTO2(67.0,168.0)
CALL CHAFIX(RF2,4,2)
CALL MOVTO2(93.0,168.0)
```

```
      CALL CHAFIX(RF3,4,2)
      CALL MOVTO2(119.0,168.0)
      CALL CHAFIX(RF4,4,2)
      CALL MOVTO2(145.0,168.0)
      CALL CHAFIX(RF5,4,2)
      CALL MOVTO2(20.0,160.0)
      CALL CHAHOL(7HCLOUD*.)
      CALL MOVTO2(40.0,160.0)
      CALL CHAINT(L1,3)
      CALL MOVTO2(93.0,160.0)
      CALL CHAINT(L2,3)
      CALL MOVTO2(119.0,160.0)
      CALL CHAINT(L3,3)
      CALL MOVTO2(145.0,160.0)
      CALL CHAINT(L4,3)
      CALL MOVTO2(43.0,152.0)
      CALL CHAARR(IT(1),1,3)
      CALL MOVTO2(96.0,152.0)
      CALL CHAARR(IT(2),1,3)
      CALL MOVTO2(122.0,152.0)
      CALL CHAARR(IT(3),1,3)
      CALL MOVTO2(148.0,152.0)
      CALL CHAARR(IT(4),1,3)
      CALL PENSEL(1,0.1,4)
      CALL AXIPOS(1,20.0,20.0,160.0,1)
      CALL AXIPOS(1,20.0,20.0,100.0,2)
      CALL AXISCA(3,24,0.0,24.0,1)
      CALL AXISCA(3,30,-10.0,20.0,2)
      CALL AXIDRA(+1,+1,1)
      CALL AXIDRA(-1,-1,2)
      CALL MOVTO2(18.0,126.0)
      CALL CHAHOL(24HSURFACE TEMPERATURE 'C*.)
      CALL MOVTO2(140.0,12.0)
      CALL CHAHOL(15HTIME IN HOURS*.)
      CALL MOVTO2(13.0,12.0)
      CALL CHAHOL(6HNOON*.)
      CALL MOVTO2(90.0,12.0)
      CALL CHAHOL(10HMIDNIGHT*.)
      CALL MOVTO2(30.0,120.0)
      CALL CHAHOL(50HACTUAL VERSUS PREDICTED ROAD SURFACE TEMPERATURE*.)
      CALL MOVTO2(30.0,118.0)
      CALL LINTO2(156.0,118.0)
      CALL PENSEL(5,0.1,4)
      CALL MOVTO2(20.0,53.5)
      CALL LINTO2(180.0,53.5)
      CALL PENSEL(2,0.1,4)
      CALL GRAPOL(TIME,TD,72)
      CALL MOVTO2(80.0,110.0)
```

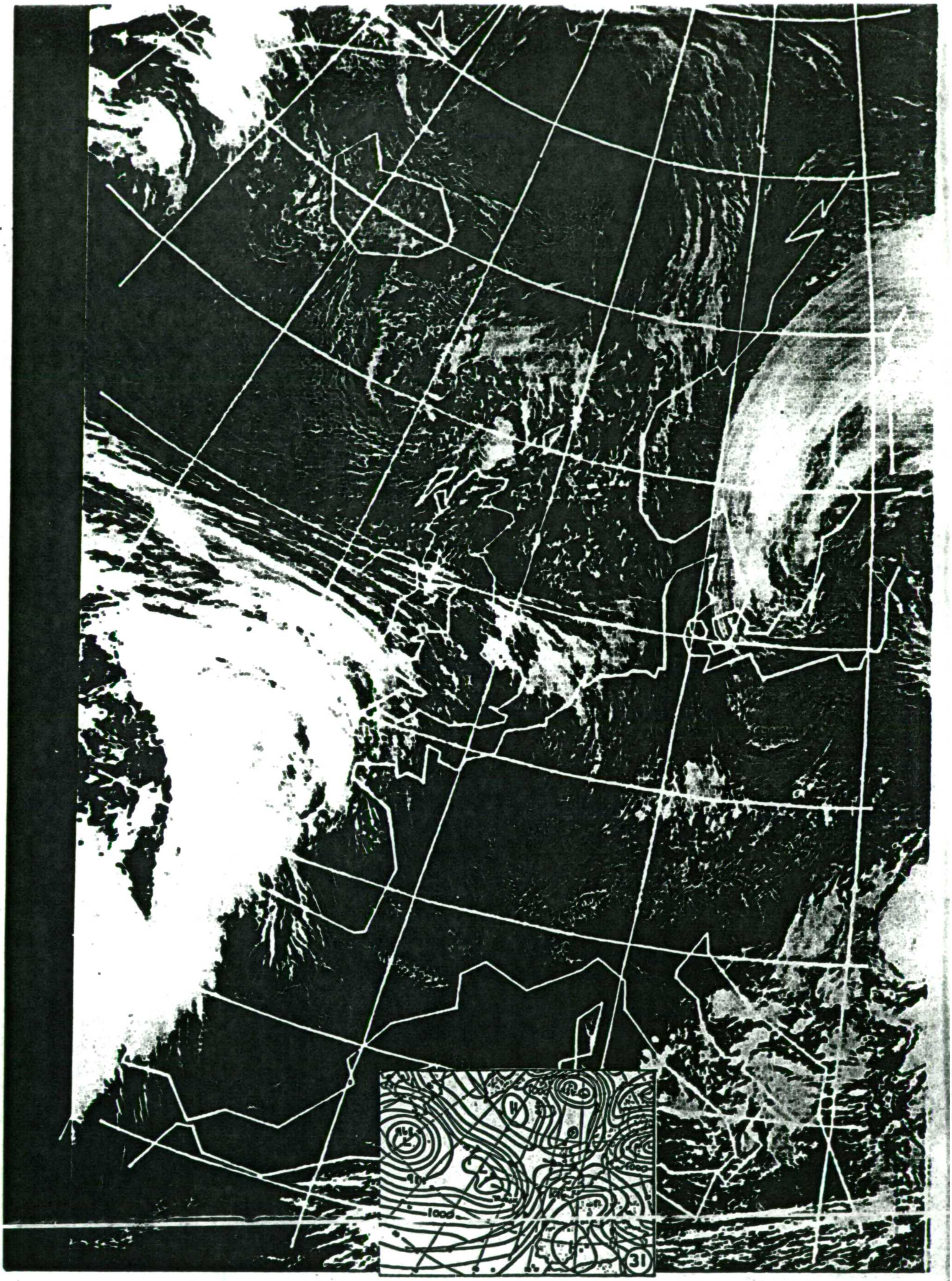
```
CALL LINTO2(90.0,110.0)
CALL MOVTO2(92.0,110.0)
CALL CHAHOL(11HPREDICTED*.)
CALL PENSEL(4,0.1,4)
CALL GRAPOL(TIME,AT,72)
CALL MOVTO2(80.0,100.0)
CALL LINTO2(90.0,100.0)
CALL MOVTO2(92.0,100.0)
CALL CHAHOL(8HACTUAL*.)
CALL PENSEL(3,0.1,4)
CALL GRAPOL(TIME,AIR,72)
CALL MOVTO2(80.0,90.0)
CALL LINTO2(90.0,90.0)
CALL MOVTO2(92.0,90.0)
CALL CHAHOL(5HAIR*.)
CALL PENSEL(1,0.1,4)
CALL GRAPOL(TIME,SLAB,72)
CALL MOVTO2(80.0,80.0)
CALL LINTO2(90.0,80.0)
CALL MOVTO2(92.0,80.0)
CALL CHAHOL(6HSLAB*.)
CALL DEVEND
CALL T4010
CALL PENSEL(1,0.1,4)
CALL AXIPOS(1,20.0,140.0,160.0,1)
CALL AXIPOS(1,20.0,140.0,100.0,2)
CALL AXISCA(3,24,0.0,24.0,1)
CALL AXISCA(3,20,-300.0,300.0,2)
CALL AXIDRA(+1,+1,1)
CALL AXIDRA(-1,-1,2)
CALL MOVTO2(20.0,190.0)
CALL LINTO2(180.0,190.0)
CALL MOVTO2(140.0,130.0)
CALL CHAHOL(15HTIME IN HOURS*.)
CALL MOVTO2(18.0,243.0)
CALL CHAHOL(17HFLUX IN MLY/MIN*.)
CALL MOVTO2(60.0,243.0)
CALL CHAHOL(41HGRAPH OF TERMS IN HEAT BALANCE EQUATION*.)
CALL MOVTO2(60.0,241.0)
CALL LINTO2(162.0,241.0)
CALL WINDO2(20.0,180.0,140.0,240.0)
CALL PENSEL(2,0.1,4)
CALL GRAPOL(TIME,RN,72)
CALL PENSEL(3,0.1,4)
CALL GRAPOL(TIME,S,72)
CALL PENSEL(4,0.1,4)
CALL GRAPOL(TIME,H,72)
CALL PENSEL(1,0.1,4)
```

```
CALL GRAPOL(TIME,LE,72)
CALL MOVTO2(30.0,233.0)
CALL CHAHOL(5HKEY*.)
CALL MOVTO2(40.0,233.0)
CALL LINTO2(45.0,233.0)
CALL MOVTO2(47.0,233.0)
CALL CHAHOL(4HLE*.)
CALL PENSEL(2,0.1,4)
CALL MOVTO2(57.0,233.0)
CALL LINTO2(62.0,233.0)
CALL MOVTO2(64.0,233.0)
CALL CHAHOL(4HRN*.)
CALL PENSEL(3,0.1,4)
CALL MOVTO2(74.0,233.0)
CALL LINTO2(79.0,233.0)
CALL MOVTO2(81.0,233.0)
CALL CHAHOL(3HS*.)
CALL PENSEL(4,0.1,4)
CALL MOVTO2(90.0,233.0)
CALL LINTO2(95.0,233.0)
CALL MOVTO2(97.0,233.0)
CALL CHAHOL(3HH*.)
CALL WINDOW(2)
CALL PENSEL(1,0.1,4)
CALL MOVTO2(56.0,2.0)
CALL CHAA1(TITLE,20)
CALL MOVTO2(56.0,1.0)
CALL LINTO2(109.0,1.0)
CALL AXIPOS(1,20.0,20.0,160.0,1)
CALL AXIPOS(1,20.0,20.0,100.0,2)
CALL AXISCA(3,24,0.0,24.0,1)
CALL AXISCA(3,30,-10.0,20.0,2)
CALL AXIDRA(+1,+1,1)
CALL AXIDRA(-1,-1,2)
CALL MOVTO2(18.0,126.0)
CALL CHAHOL(17H TEMPERATURE 'C*.)
CALL MOVTO2(140.0,12.0)
CALL CHAHOL(15HTIME IN HOURS*.)
CALL MOVTO2(13.0,12.0)
CALL CHAHOL(6HNOON*.)
CALL MOVTO2(90.0,12.0)
CALL CHAHOL(10HMIDNIGHT*.)
CALL MOVTO2(30.0,120.0)
CALL CHAHOL(46HACTUAL VERSUS PREDICTED SUB ROAD TEMPERATURE*.)
CALL MOVTO2(30.0,118.0)
CALL LINTO2(145.0,118.0)
CALL GRAPOL(TIME,T35,72)
CALL MOVTO2(40.0,110.0)
```

```
CALL LINTO2(50.0,110.0)
CALL MOVTO2(52.0,110.0)
CALL CHAHOL(16HPREDICTED 36cm*.)
CALL PENSEL(2,0.1,4)
CALL GRAPOL(TIME,T36,72)
CALL MOVTO2(40.0,100.0)
CALL LINTO2(50.0,100.0)
CALL MOVTO2(52.0,100.0)
CALL CHAHOL(13HACTUAL 36cm*.)
CALL PENSEL(3,0.1,4)
CALL GRAPOL(TIME,T18,72)
CALL MOVTO2(100.0,110.0)
CALL LINTO2(110.0,110.0)
CALL MOVTO2(112.0,110.0)
CALL CHAHOL(16HPREDICTED 18cm*.)
CALL PENSEL(4,0.1,4)
CALL GRAPOL(TIME,T17,72)
CALL MOVTO2(100.0,100.0)
CALL LINTO2(110.0,100.0)
CALL MOVTO2(112.0,100.0)
CALL CHAHOL(13HACTUAL 18cm*.)
CALL DEVEND
```

APPENDIX 2

Additional Results and Original Data for 30 Nights Considered in Chapter 6 (see page 160)



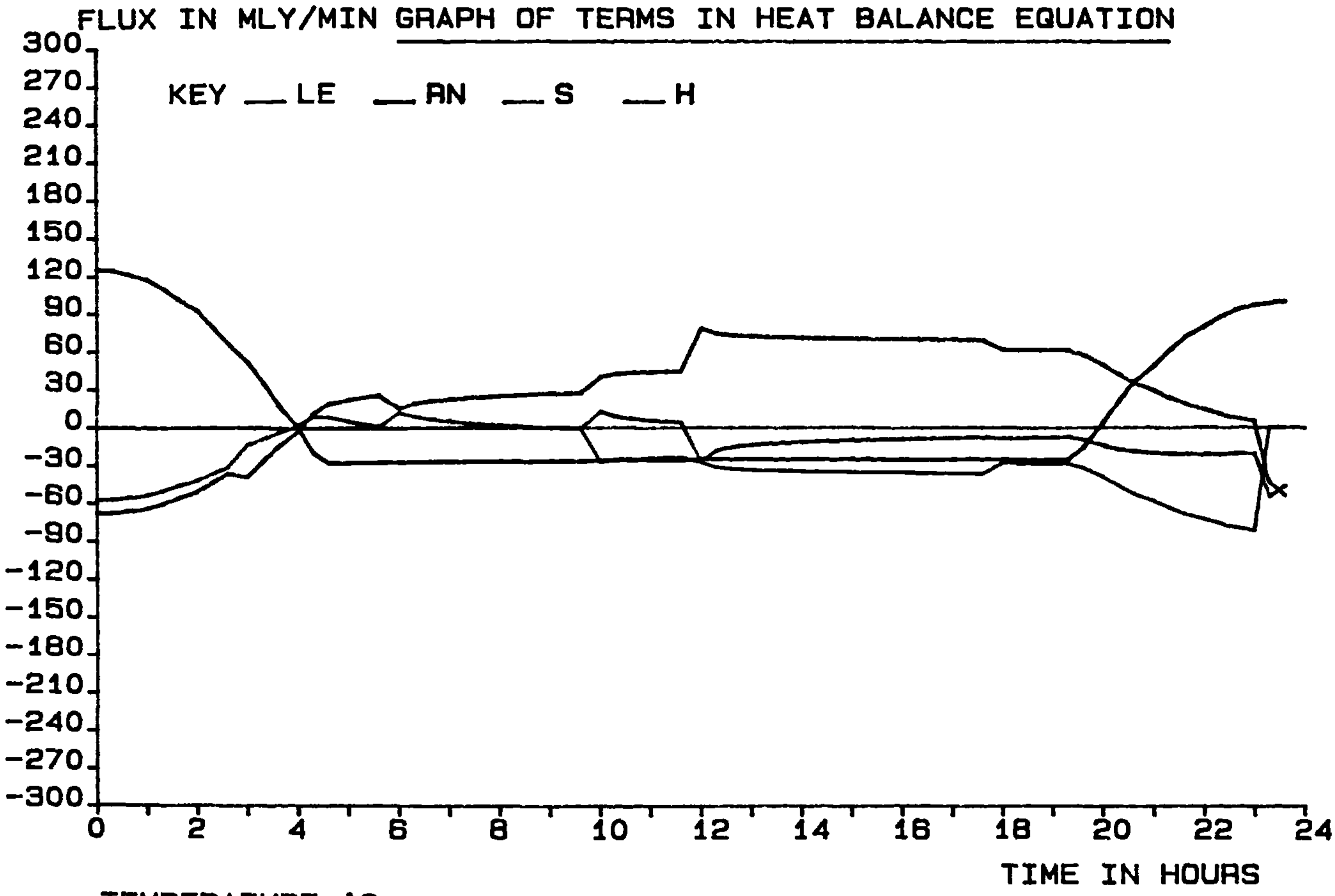
31-01-79

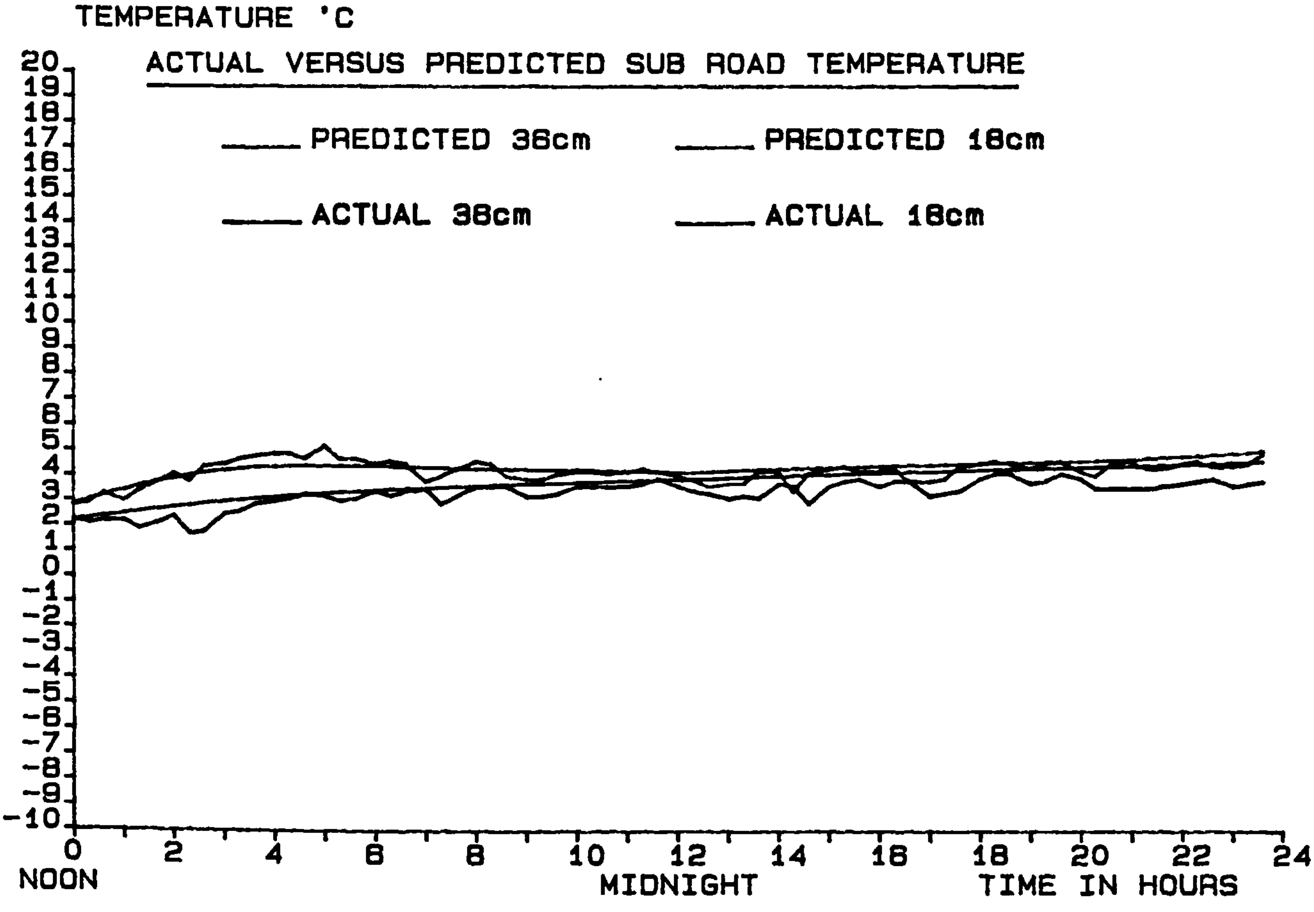
COMPUTED DATA
SAT. VAP. PRESSURE(MB)= 9.54
VAPOUR PRESSURE(MB)= 7.44
REL. HUMIDITY FRACTION = 0.78
APPROX. PRECIP. WATER(MM)= 11.8
ROAD DAMPING DEPTH(CM)= 72.
AIR DAMPING DEPTH(CM)= 2642. 3258.
AIR HEAT TRANSFER COEF.(CGS)= 0.00260 0.00380

DEC	R	T36	T18	TS	UA	D	TIME WET
-17.197	0.985	275.4	276.0	7.5	435. 688.	0.5	22

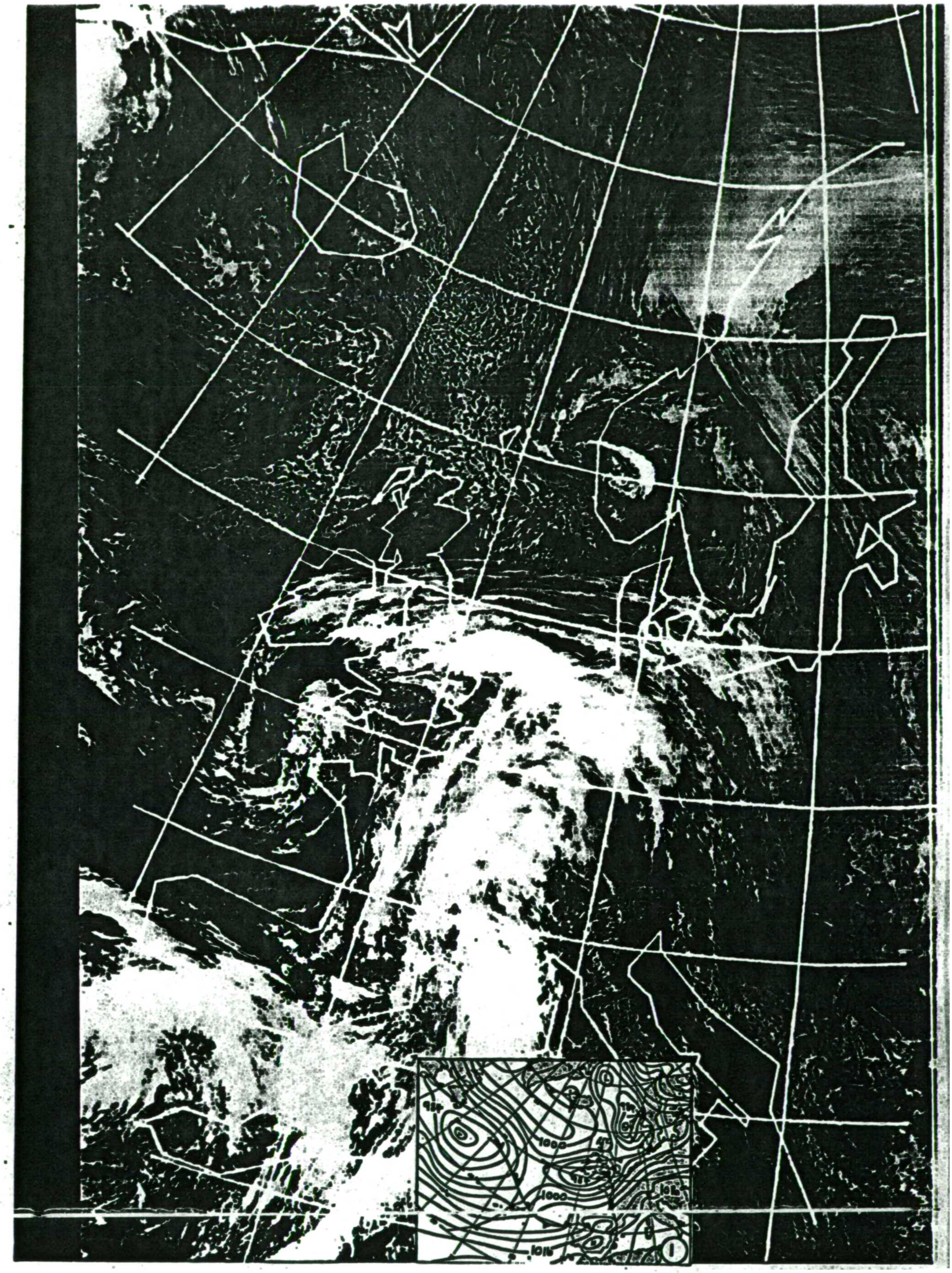
SOLAR TIME	SUN	RN	S	H	LE	TD	TC	SUM	RI	~~TO~~	T36	Air	T18	~~Tslab~~
	(ALL MLY./MIN.)					(C.)								
12.0	251.0	125.7	-58.	-68.	0.	7.50	8.38	1.	-0.00017	7.50	2.20	6.70	2.80	6.80
12.0	250.3	124.7	-58.	-68.	0.	7.94	8.38	0.	-0.00017	7.80	2.10	6.90	2.90	7.10
12.0	248.3	121.9	-56.	-67.	0.	8.14	8.34	0.	-0.00017	8.50	2.20	6.80	3.30	8.00
13.0	244.9	117.2	-54.	-64.	0.	8.21	8.28	0.	-0.00016	9.00	2.20	6.70	3.00	8.70
13.0	240.1	110.6	-51.	-61.	0.	8.20	8.19	0.	-0.00015	8.60	1.90	6.30	3.40	7.90
13.0	234.0	102.2	-47.	-56.	0.	8.13	8.07	0.	-0.00014	8.50	2.10	6.10	3.70	7.30
14.0	226.3	92.1	-42.	-51.	0.	8.03	7.92	0.	-0.00013	8.00	2.40	6.20	4.10	6.60
14.0	217.1	80.2	-37.	-44.	0.	7.89	7.74	0.	-0.00011	7.10	1.70	5.60	3.80	5.90
14.0	206.1	66.7	-31.	-36.	0.	7.71	7.54	0.	-0.00009	7.10	1.80	5.70	4.40	6.10
15.0	192.9	51.6	-13.	-39.	0.	7.36	7.01	0.	-0.00010	7.70	2.50	6.60	4.50	6.50
15.0	176.8	35.5	-9.	-27.	0.	7.02	6.69	0.	-0.00007	7.40	2.00	6.40	4.70	5.90
15.0	155.8	18.2	-4.	-15.	0.	6.70	6.37	0.	-0.00004	7.20	2.90	6.30	4.80	5.60
16.0	124.6	0.0	2.	-3.	0.	6.37	6.04	0.	-0.00001	6.80	3.00	6.00	4.90	5.10
16.0	58.4	-19.6	8.	10.	0.	6.03	5.69	0.	0.00003	6.30	3.10	5.60	4.90	4.50
16.0	0.0	-27.6	8.	18.	0.	5.75	5.47	0.	0.00005	6.00	3.30	5.50	4.70	4.30
17.0	0.0	-27.4	5.	22.	0.	5.57	5.38	0.	0.00006	5.60	3.20	5.20	5.20	3.60
17.0	0.0	-27.3	3.	24.	0.	5.45	5.33	0.	0.00006	5.10	3.00	5.00	4.70	3.10
17.0	0.0	-27.2	1.	25.	0.	5.37	5.29	0.	0.00007	5.20	3.10	5.00	4.70	3.20
18.0	0.0	-27.2	11.	15.	0.	5.17	4.97	0.	0.00004	5.30	3.40	3.10	4.50	3.40
18.0	0.0	-27.0	8.	19.	0.	5.02	4.87	0.	0.00005	4.70	3.20	3.70	4.60	2.70
18.0	0.0	-26.9	6.	21.	0.	4.92	4.81	0.	0.00005	4.90	3.40	4.90	4.50	3.10
19.0	0.0	-26.8	5.	22.	0.	4.85	4.78	0.	0.00006	5.00	3.50	4.90	3.80	3.10
19.0	0.0	-26.7	4.	23.	0.	4.80	4.75	0.	0.00006	4.30	2.90	4.70	4.00	2.50
19.0	0.0	-26.7	3.	24.	0.	4.76	4.72	0.	0.00006	4.60	3.20	5.10	4.30	3.00
20.0	0.0	-26.6	2.	25.	0.	4.73	4.70	0.	0.00006	4.60	3.60	5.10	4.60	2.90
20.0	0.0	-26.6	1.	26.	0.	4.71	4.68	0.	0.00007	4.70	3.60	5.40	4.50	3.00
20.0	0.0	-26.6	0.	26.	0.	4.69	4.67	0.	0.00007	4.50	3.60	5.10	4.00	2.00
21.0	0.0	-26.5	0.	27.	0.	4.67	4.65	0.	0.00007	3.90	3.20	4.50	3.90	2.20
21.0	0.0	-26.5	-1.	27.	0.	4.66	4.64	0.	0.00007	3.90	3.20	4.60	3.90	2.40
21.0	0.0	-26.5	-1.	27.	0.	4.64	4.63	0.	0.00007	4.00	3.30	5.00	4.10	2.60
22.0	0.0	-25.8	13.	40.	-27.	4.46	4.29	-27.	0.00010	4.30	3.60	5.50	4.20	2.90
22.0	0.0	-25.6	9.	42.	-25.	4.35	4.23	-52.	0.00011	4.40	3.60	5.80	4.20	3.10
22.0	0.0	-25.6	7.	43.	-24.	4.28	4.20	-77.	0.00011	4.50	3.60	6.00	4.10	3.40
23.0	0.0	-25.6	5.	44.	-24.	4.23	4.19	-101.	0.00011	4.60	3.60	6.20	4.20	3.50
23.0	0.0	-25.5	5.	44.	-24.	4.20	4.18	-124.	0.00011	4.80	3.70	6.50	4.30	4.00
23.0	0.0	-25.5	4.	45.	-23.	4.19	4.17	-148.	0.00012	5.00	3.90	6.50	4.20	4.10
0.0	0.0	-24.7	-27.	79.	-27.	4.54	4.89	-175.	0.00006	4.70	3.60	6.40	4.00	3.70
0.0	0.0	-24.9	-18.	75.	-31.	4.75	4.96	-206.	0.00005	4.50	3.40	6.10	3.90	3.60
0.0	0.0	-24.9	-15.	73.	-33.	4.87	4.99	-239.	0.00005	4.40	3.30	6.10	3.60	3.60
1.0	0.0	-25.0	-14.	72.	-33.	4.94	5.01	-273.	0.00005	4.20	3.10	6.00	3.70	3.40
1.0	0.0	-25.0	-13.	72.	-34.	4.98	5.02	-306.	0.00005	4.30	3.20	5.90	3.70	3.50
1.0	0.0	-25.0	-12.	71.	-34.	5.00	5.02	-341.	0.00005	4.20	3.10	5.80	4.20	3.50
2.0	0.0	-25.0	-11.	71.	-35.	5.01	5.03	-375.	0.00005	4.80	3.70	6.20	4.20	4.20
2.0	0.0	-25.0	-11.	71.	-35.	5.02	5.03	-410.	0.00005	4.80	3.60	6.40	3.40	4.20
2.0	0.0	-25.0	-10.	70.	-35.	5.03	5.04	-445.	0.00005	4.00	2.90	5.50	4.10	3.40
3.0	0.0	-25.0	-10.	70.	-35.	5.04	5.04	-480.	0.00005	4.80	3.60	6.20	4.30	4.30
3.0	0.0	-25.1	-9.	70.	-35.	5.04	5.05	-516.	0.00005	5.00	3.80	6.40	4.40	4.40
3.0	0.0	-25.1	-9.	70.	-36.	5.05	5.05	-551.	0.00005	5.00	3.90	6.40	4.20	4.50
4.0	0.0	-25.1	-9.	70.	-36.	5.05	5.05	-587.	0.00005	4.80	3.60	6.20	4.20	4.30
4.0	0.0	-25.1	-8.	70.	-36.	5.05	5.06	-623.	0.00005	5.00	3.80	6.30	4.30	4.50
4.0	0.0	-25.1	-8.	69.	-36.	5.06	5.06	-659.	0.00005	5.00	3.80	6.10	3.60	4.50
5.0	0.0	-25.1	-8.	69.	-36.	5.06	5.06	-695.	0.00005	4.30	3.20	5.20	3.60	3.80
5.0	0.0	-25.1	-8.	69.	-36.	5.06	5.06	-732.	0.00005	4.40	3.30	5.00	3.90	3.60
5.0	0.0	-25.1	-7.	69.	-36.	5.06	5.06	-768.	0.00005	4.50	3.40	5.10	4.40	4.00
6.0	0.0	-25.2	-9.	62.	-28.	5.08	5.10	-796.	0.00004	5.00	3.90	5.70	4.50	4.50
6.0	0.0	-25.2	-8.	61.	-28.	5.09	5.11	-824.	0.00004	5.30	4.10	6.20	4.00	4.80
6.0	0.0	-25.2	-8.	61.	-28.	5.10	5.11	-852.	0.00004	5.30	4.10	6.00	4.50	4.60
7.0	0.0	-25.2	-7.	61.	-28.	5.11	5.11	-880.	0.00004	5.10	3.70	5.80	4.30	4.50
7.0	0.0	-25.2	-7.	61.	-28.	5.11	5.12	-908.	0.00004	5.30	3.80	6.00	4.50	4.60
7.0	63.8	-15.8	-10.	57.	-32.	5.15	5.18	-940.	0.00004	5.60	4.10	6.20	4.60	4.70
8.0	123.9	3.6	-14.	49.	-39.	5.23	5.32	-979.	0.00004	5.60	3.90	6.00	4.20	4.80
8.0	149.3	20.5	-17.	42.	-46.	5.35	5.46	-1025.	0.00003	5.20	3.50	5.60	4.00	4.50
8.0	164.4	35.7	-19.	35.	-52.	5.46	5.56	-1077.	0.00003	5.20	3.50	5.50	4.50	4.40
9.0	174.6	49.1	-20.	29.	-58.	5.58	5.70	-1135.	0.00002	5.70	3.50	5.80	4.60	4.90
9.0	182.5	60.9	-21.	23.	-64.	5.69	5.80	-1199.	0.00002	5.40	3.50	5.50	4.30	4.70
9.0	188.5	71.1	-21.	19.	-68.	5.79	5.89	-1267.	0.00001	5.40	[illegible]	[illegible]	4.30	4.60
10.0	193.3	79.8	-21.	14.	-73.	5.88	5.97	[illegible]	0.00001	5.60	3.70	5.80	4.50	4.90
10.0	197.0	87.0	[illegible]	[illegible]	-76.	5.95	6.03	-1416.	0.00001	5.70	3.80	6.00	4.60	5.10
10.0	199.9	92.8	-21.	7.	-79.	6.02	6.09	-1495.	0.00001	6.00	3.90	6.40	4.40	5.30
11.0	202.1	97.3	-21.	5.	-82.	6.06	6.14	-1576.	0.00000	5.80	3.60	6.00	4.40	5.20
11.0	203.6	96.6	-55.	-44.	0.	6.55	7.03	-1576.	-0.00003	5.90	3.70	6.00	4.50	5.20
11.0	204.5	100.1	-47.	-54.	0.	6.89	7.22	-1576.	-0.00004	5.90	3.80	6.00	4.90	5.40

Model Output 31-01-79 Actuals





31-01 FEBRUARY 1979



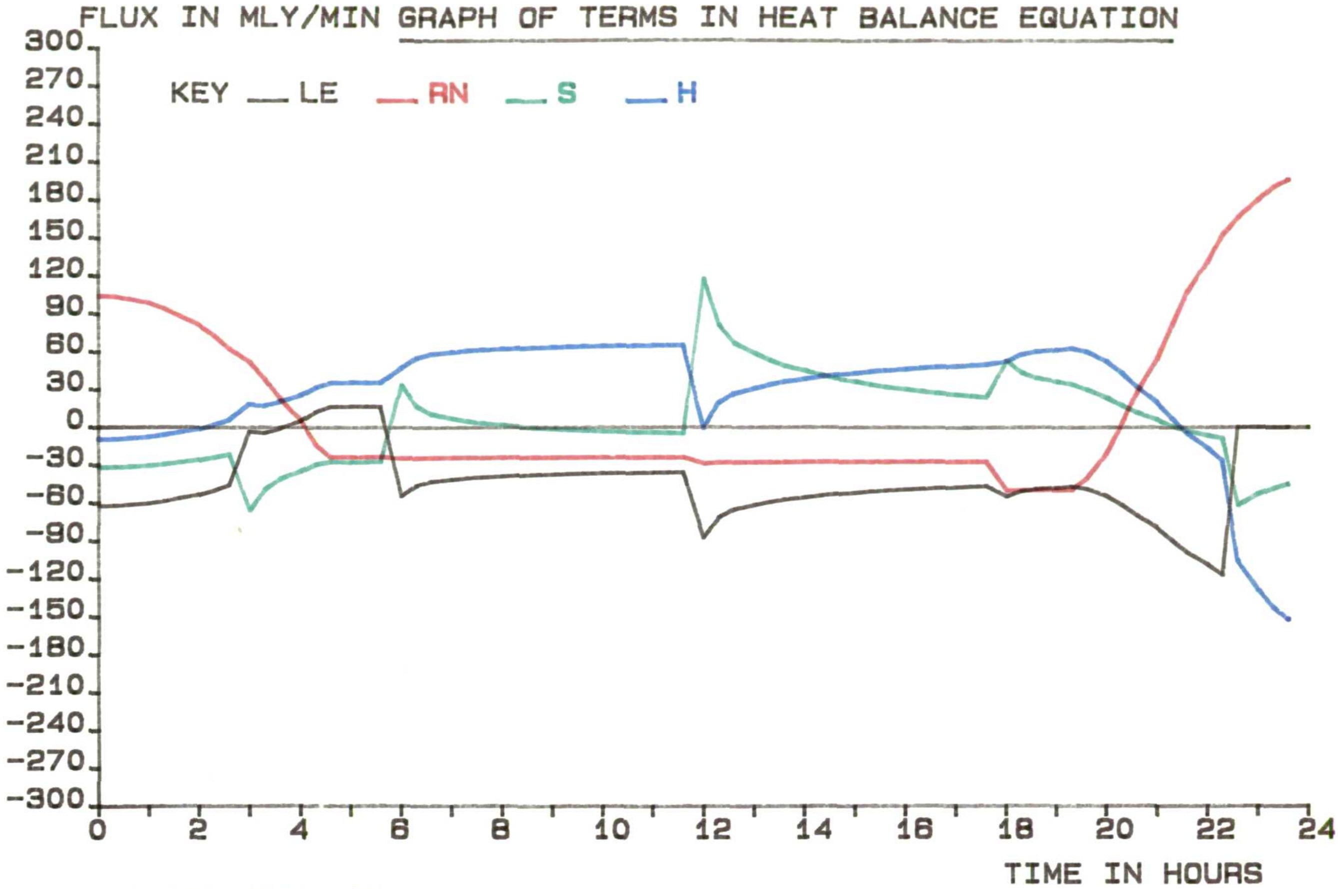
01-02-79

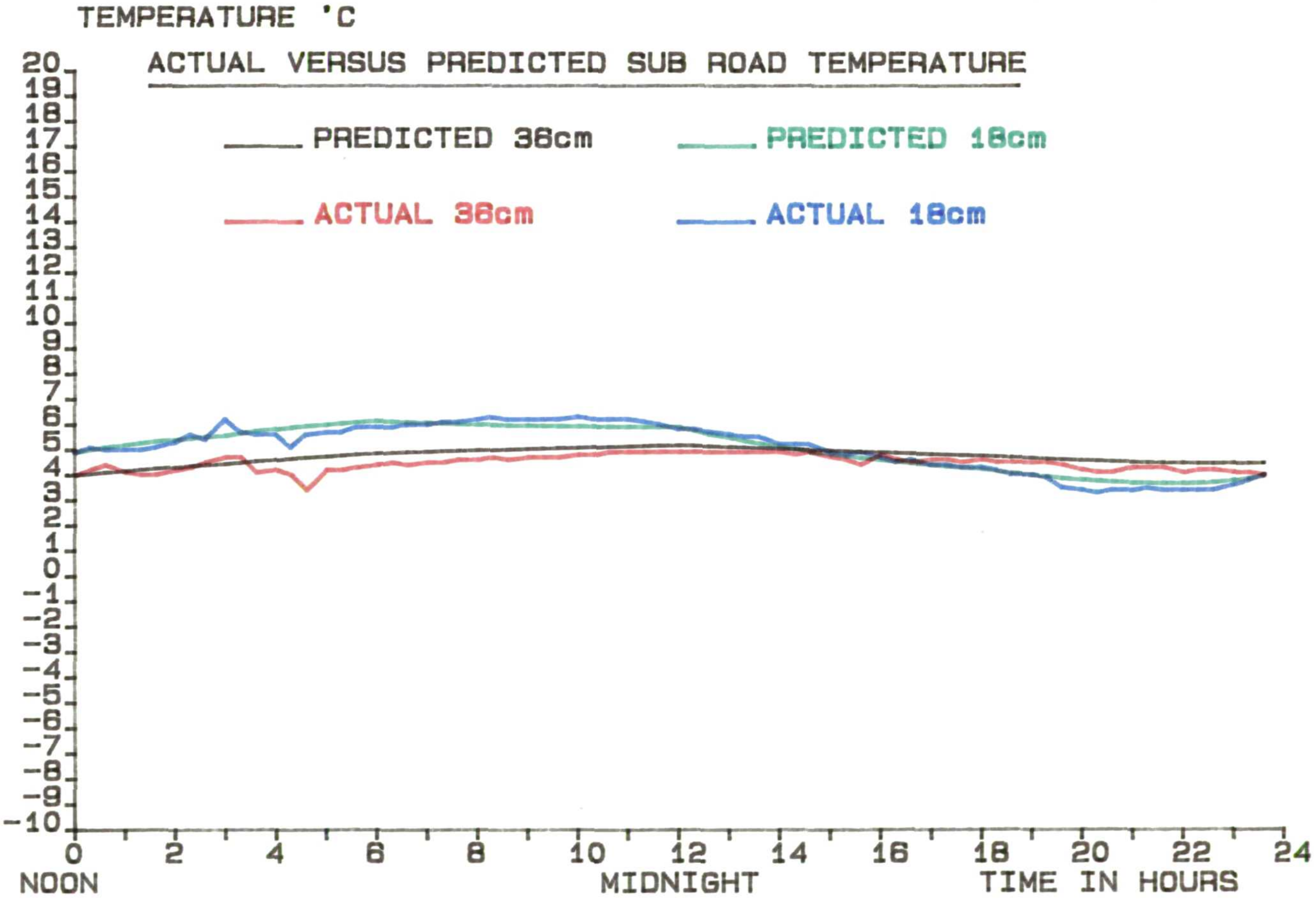
COMPUTED DATA
SAT. VAP. PRESSURE(MB)= 10.36
VAPOUR PRESSURE(MB)= 9.84
REL. HUMIDITY FRACTION = 0.95
APPROX. PRECIP. WATER(MM)= 15.4
ROAD DAMPING DEPTH(CM)= 72.
AIR DAMPING DEPTH(CM)= 2996. 3303.
AIR HEAT TRANSFER COEF.(CGS)= 0.00327 0.00390

DEC	R	T36	T18	TS	UA	D	TIME WET
-16.912	0.986	277.2	278.1	6.3	573. 709.	0.5	12

SOLAR TIME	SUN	RN	S	H	LE	TO	TC	SUM	RI	TO	T36	Air	T18	Tslab
			(ALL MLY./MIN.)				(C.)							
12.0	204.9	103.6	-32.	-9.	-62.	6.30	8.00	-61.	-0.00001	6.30	4.00	6.30	4.90	5.60
12.0	204.6	103.0	-32.	-9.	-62.	7.15	7.99	-62.	-0.00001	6.50	4.20	6.60	5.10	5.80
12.0	203.7	101.1	-31.	-8.	-61.	7.56	7.98	-123.	-0.00001	7.10	4.40	7.10	5.00	6.30
13.0	202.2	98.0	-30.	-7.	-60.	7.76	7.96	-183.	-0.00001	7.00	4.10	7.10	5.00	6.50
13.0	200.0	93.6	-29.	-6.	-58.	7.84	7.92	-242.	-0.00001	7.00	4.00	7.40	5.00	6.40
13.0	197.1	87.7	-28.	-4.	-56.	7.86	7.88	-298.	0.00000	7.10	4.00	7.80	5.10	6.50
14.0	193.4	80.6	-26.	-1.	-53.	7.84	7.83	-351.	0.00000	7.40	4.20	8.10	5.30	6.90
14.0	188.7	71.9	-24.	2.	-50.	7.80	7.76	-401.	0.00000	7.60	4.30	8.40	5.60	6.80
14.0	182.7	61.7	-22.	6.	-46.	7.74	7.68	-447.	0.00001	7.90	4.50	8.80	5.40	7.40
15.0	175.0	51.1	-66.	18.	-3.	8.23	8.71	-450.	0.00002	8.20	4.70	9.10	6.20	7.60
15.0	164.7	37.4	-49.	17.	-5.	8.48	8.74	-455.	0.00002	8.20	4.70	9.20	5.70	7.60
15.0	149.8	22.2	-41.	20.	-1.	8.58	8.67	-456.	0.00002	7.70	4.10	8.80	5.60	7.30
16.0	124.9	5.3	-35.	25.	5.	8.57	8.57	-452.	0.00003	7.80	4.20	8.70	5.60	7.10
16.0	67.0	-14.0	-29.	32.	12.	8.50	8.43	-440.	0.00004	7.60	4.00	8.60	5.10	6.90
16.0	0.0	-24.0	-27.	35.	16.	8.43	8.35	-424.	0.00004	7.20	3.40	8.20	5.60	6.80
17.0	0.0	-24.0	-28.	36.	16.	8.38	8.34	-407.	0.00004	7.80	4.20	8.80	5.70	7.20
17.0	0.0	-24.0	-28.	35.	16.	8.37	8.35	-391.	0.00004	7.80	4.20	8.90	5.70	7.20
17.0	0.0	-24.0	-27.	35.	16.	8.36	8.35	-375.	0.00004	7.90	4.30	9.10	5.90	7.40
18.0	0.0	-25.1	33.	47.	-55.	7.63	6.91	-430.	0.00006	8.00	4.40	9.20	5.90	7.40
18.0	0.0	-24.7	16.	55.	-46.	7.18	6.74	-476.	0.00007	8.10	4.50	9.20	5.90	7.30
18.0	0.0	-24.6	10.	58.	-43.	6.93	6.67	-519.	0.00007	8.00	4.40	9.00	6.00	7.40
19.0	0.0	-24.5	7.	59.	-41.	6.78	6.64	-561.	0.00007	8.00	4.50	9.20	6.00	7.60
19.0	0.0	-24.4	4.	61.	-40.	6.70	6.61	-601.	0.00007	8.00	4.50	9.20	6.10	7.40
19.0	0.0	-24.4	3.	61.	-40.	6.65	6.60	-640.	0.00007	8.10	4.60	9.10	6.10	7.40
20.0	0.0	-24.4	1.	62.	-39.	6.61	6.58	-679.	0.00007	8.00	4.60	8.80	6.20	7.30
20.0	0.0	-24.3	0.	63.	-38.	6.59	6.57	-718.	0.00008	8.00	4.70	9.00	6.30	7.20
20.0	0.0	-24.3	-1.	63.	-38.	6.57	6.56	-755.	0.00008	8.10	4.60	8.40	6.20	7.00
21.0	0.0	-24.3	-2.	63.	-37.	6.56	6.55	-793.	0.00008	7.80	4.70	7.90	6.20	6.80
21.0	0.0	-24.3	-2.	64.	-37.	6.55	6.54	-830.	0.00008	7.70	4.70	8.00	6.20	6.80
21.0	0.0	-24.3	-3.	64.	-37.	6.54	6.54	-867.	0.00008	7.60	4.70	8.00	6.20	6.90
22.0	0.0	-24.3	-4.	64.	-37.	6.54	6.53	-903.	0.00008	7.60	4.80	6.70	6.30	6.80
22.0	0.0	-24.2	-4.	65.	-36.	6.53	6.53	-940.	0.00008	7.10	4.80	5.80	6.20	6.30
22.0	0.0	-24.2	-4.	65.	-36.	6.53	6.52	-976.	0.00008	7.00	4.90	5.40	6.20	5.90
23.0	0.0	-24.2	-5.	65.	-36.	6.52	6.52	-1012.	0.00008	6.30	4.90	5.00	6.20	5.50
23.0	0.0	-24.2	-5.	65.	-36.	6.52	6.52	-1047.	0.00008	6.30	4.90	4.70	6.10	5.20
23.0	0.0	-24.2	-5.	65.	-36.	6.52	6.51	-1083.	0.00008	6.00	4.90	4.50	6.00	5.10
0.0	0.0	-29.1	117.	-1.	-88.	5.03	3.54	-1171.	0.00000	5.50	4.90	4.20	5.80	4.70
0.0	0.0	-28.4	81.	19.	-71.	4.11	3.19	-1242.	0.00001	5.20	4.90	3.90	5.80	4.50
0.0	0.0	-28.1	66.	27.	-65.	3.58	3.06	-1307.	0.00002	5.00	4.90	3.60	5.70	4.30
1.0	0.0	-27.9	59.	31.	-62.	3.28	2.98	-1368.	0.00002	4.80	4.90	3.50	5.60	4.20
1.0	0.0	-27.8	53.	34.	-59.	3.10	2.93	-1428.	0.00002	4.60	4.90	3.20	5.50	3.90
1.0	0.0	-27.7	49.	36.	-57.	2.99	2.88	-1485.	0.00002	4.60	4.90	3.10	5.50	3.60
2.0	0.0	-27.7	45.	38.	-55.	2.92	2.85	-1540.	0.00003	4.40	4.90	3.30	5.20	3.70
2.0	0.0	-27.6	41.	40.	-54.	2.87	2.81	-1594.	0.00003	4.10	4.80	3.20	5.20	3.40
2.0	0.0	-27.5	39.	42.	-53.	2.83	2.79	-1647.	0.00003	4.10	4.90	3.20	5.20	3.50
3.0	0.0	-27.5	36.	43.	-52.	2.79	2.76	-1699.	0.00003	3.80	4.70	3.20	4.90	3.30
3.0	0.0	-27.4	34.	44.	-51.	2.77	2.74	-1749.	0.00003	3.70	4.60	3.00	4.80	3.10
3.0	0.0	-27.4	32.	45.	-50.	2.74	2.72	-1799.	0.00003	3.40	4.40	2.90	4.90	2.90
4.0	0.0	-27.4	30.	46.	-49.	2.72	2.70	-1848.	0.00003	3.70	4.80	3.10	4.70	3.00
4.0	0.0	-27.3	28.	47.	-48.	2.71	2.69	-1897.	0.00003	3.50	4.60	3.10	4.50	2.90
4.0	0.0	-27.3	27.	48.	-48.	2.69	2.67	-1945.	0.00003	3.20	4.50	2.90	4.60	2.60
5.0	0.0	-27.3	26.	49.	-47.	2.68	2.66	-1992.	0.00003	3.20	4.60	2.90	4.40	2.70
5.0	0.0	-27.3	25.	49.	-47.	2.66	2.65	-2039.	0.00003	3.00	4.60	2.80	4.40	2.50
5.0	0.0	-27.2	23.	50.	-46.	2.65	2.64	-2085.	0.00003	2.50	4.50	2.70	4.30	1.80
6.0	0.0	-50.4	53.	52.	-55.	2.28	1.90	-2139.	0.00004	2.50	4.60	2.50	4.30	1.90
6.0	0.0	-50.0	43.	58.	-51.	2.04	1.80	-2190.	0.00004	2.00	4.50	2.30	4.20	1.20
6.0	0.0	-49.9	39.	60.	-49.	1.90	1.76	-2239.	0.00004	1.80	4.50	2.10	4.00	0.90
7.0	0.0	-49.8	36.	61.	-48.	1.82	1.74	-2286.	0.00004	1.70	4.50	1.90	4.00	0.30
7.0	0.0	-49.7	34.	63.	-47.	1.77	1.72	-2333.	0.00004	1.50	4.50	1.90	3.90	0.30
7.0	58.9	-40.6	30.	60.	-49.	1.77	1.76	-2382.	0.00004	1.30	4.40	1.80	3.50	0.10
8.0	120.2	-21.1	23.	52.	-54.	1.83	1.90	-2436.	0.00004	1.10	4.20	1.40	3.40	-0.20
8.0	166.1	1.8	17.	43.	-62.	1.95	2.07	-2498.	0.00003	1.30	4.10	1.70	3.30	-0.10
8.0	206.6	27.3	11.	32.	-70.	2.10	2.26	-2568.	0.00002	1.70	4.10	1.80	3.40	0.10
9.0	243.5	54.2	6.	20.	-79.	2.29	2.48	-2647.	0.00001	2.40	4.30	2.30	3.40	0.70
9.0	277.0	81.0	1.	7.	-89.	2.50	2.70	-2737.	0.00000	2.70	4.30	2.20	3.50	1.10
9.0	307.0	107.0	-3.	-5.	-99.	2.70	2.91	-2836.	0.00000	2.80	4.30	2.20	3.40	1.40
10.0	333.6	131.2	-7.	-16.	-108.	2.91	3.12	-2944.	-0.00001	2.70	4.10	2.70	3.40	[illegible]
10.0	356.4	152.7	-9.	-27.	-117.	3.11	3.30	-3061.	-0.00002	3.90	4.20	3.10	3.40	2.70
10.0	375.3	166.2	-62.	-105.	0.	3.90	4.70	-3061.	-0.00007	5.00	4.20	3.40	3.40	4.00
11.0	390.3	180.0	-53.	-128.	0.	4.51	5.11	-3061.	-0.00009	6.10	4.10	3.80	3.00	5.10
11.0	401.0	190.1	-49.	-142.	0.	4.94	5.36	-3061.	-0.00010	6.90	4.10	4.10	3.80	5.90
11.0	407.5	196.2	-45.	-152.	0.	5.24	5.54	-3061.	-0.00010	7.50	4.00	4.30	4.00	4.90

Model Output **01-02-79** **Actuals**





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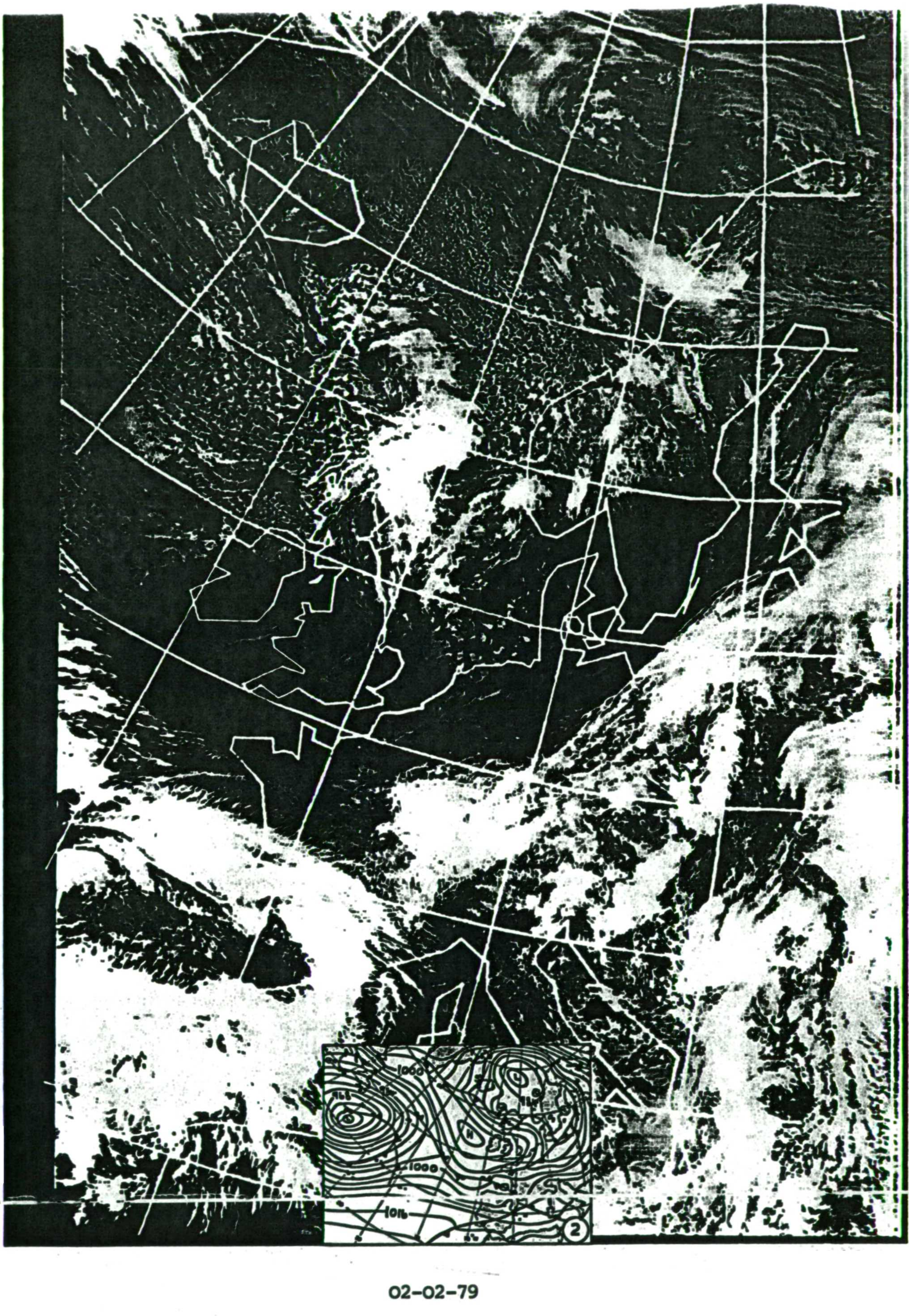


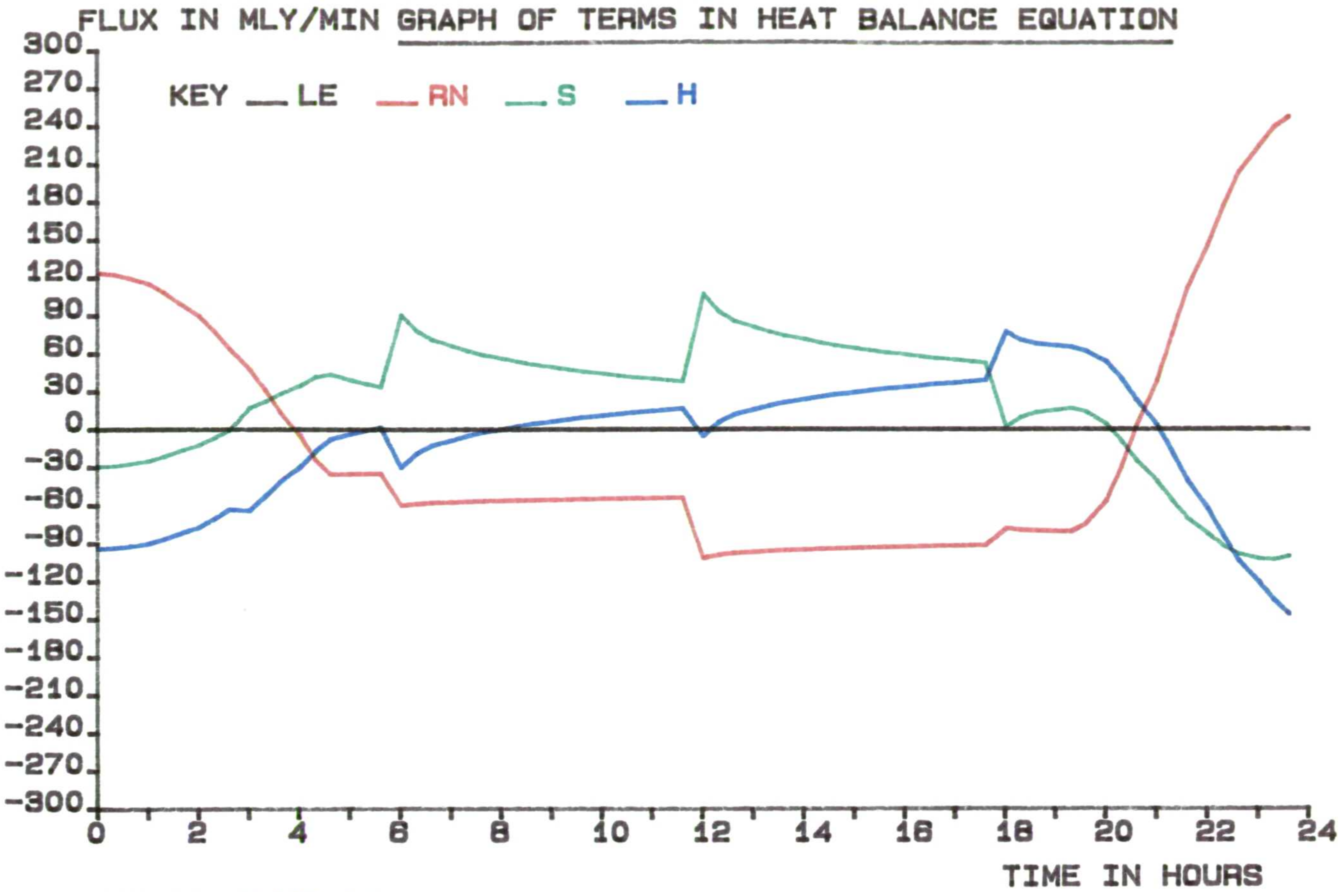
02-02-79

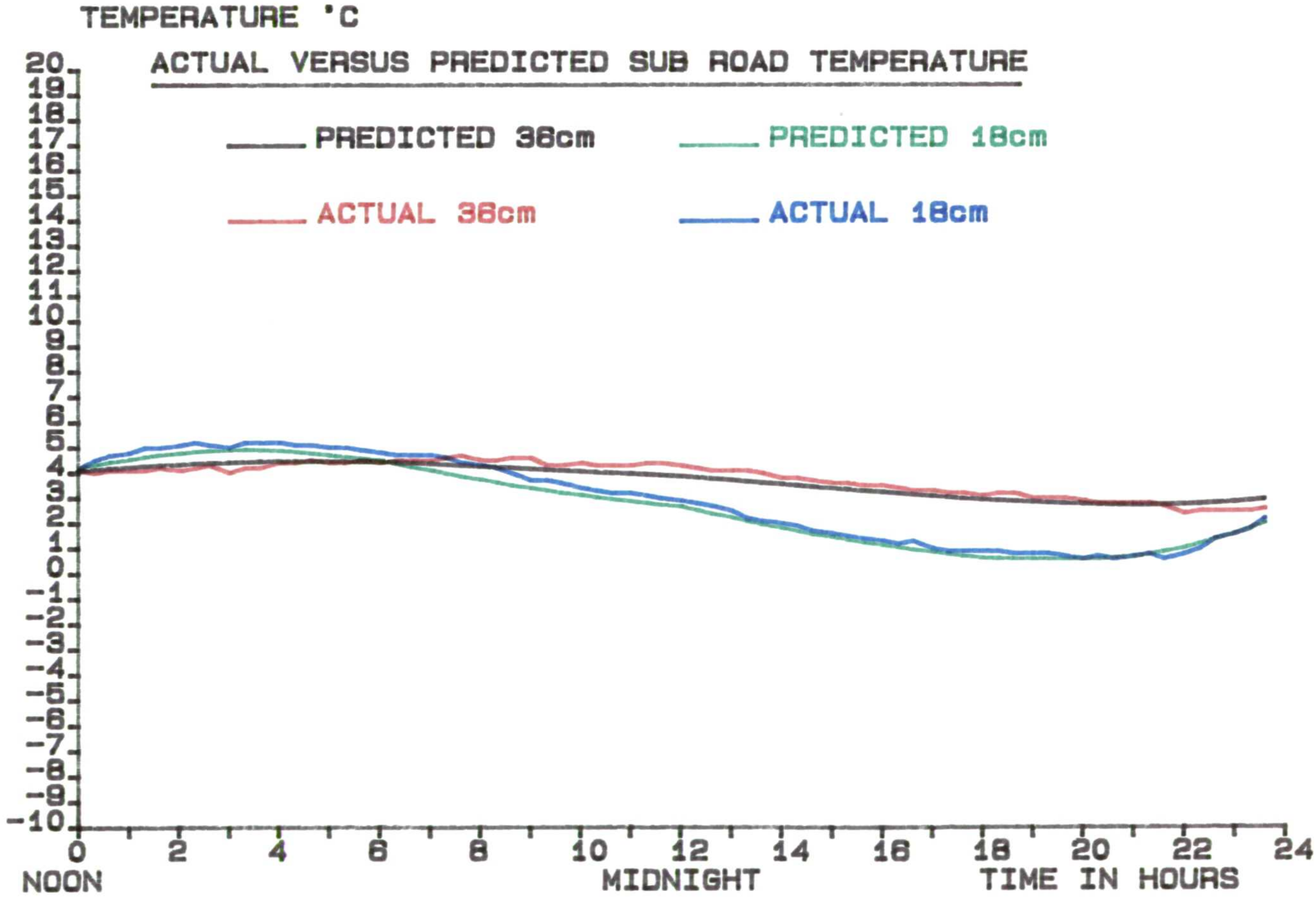
COMPUTED DATA
SAT. VAP. PRESSURE(MB)= 7.90
VAPOUR PRESSURE(MB)= 4.66
REL. HUMIDITY FRACTION = 0.59
APPROX. PRECIP. WATER(MM)= 7.6
ROAD DAMPING DEPTH(CM)= 72.
AIR DAMPING DEPTH(CM)= 2285. 2194.
AIR HEAT TRANSFER COEF.(CGS)= 0.00200 0.00186

DEC	R	T36	T18	TS	UA	D	TIME WET
-16.622	0.986	277.3	277.4	8.0	316. 289.	0.5	0

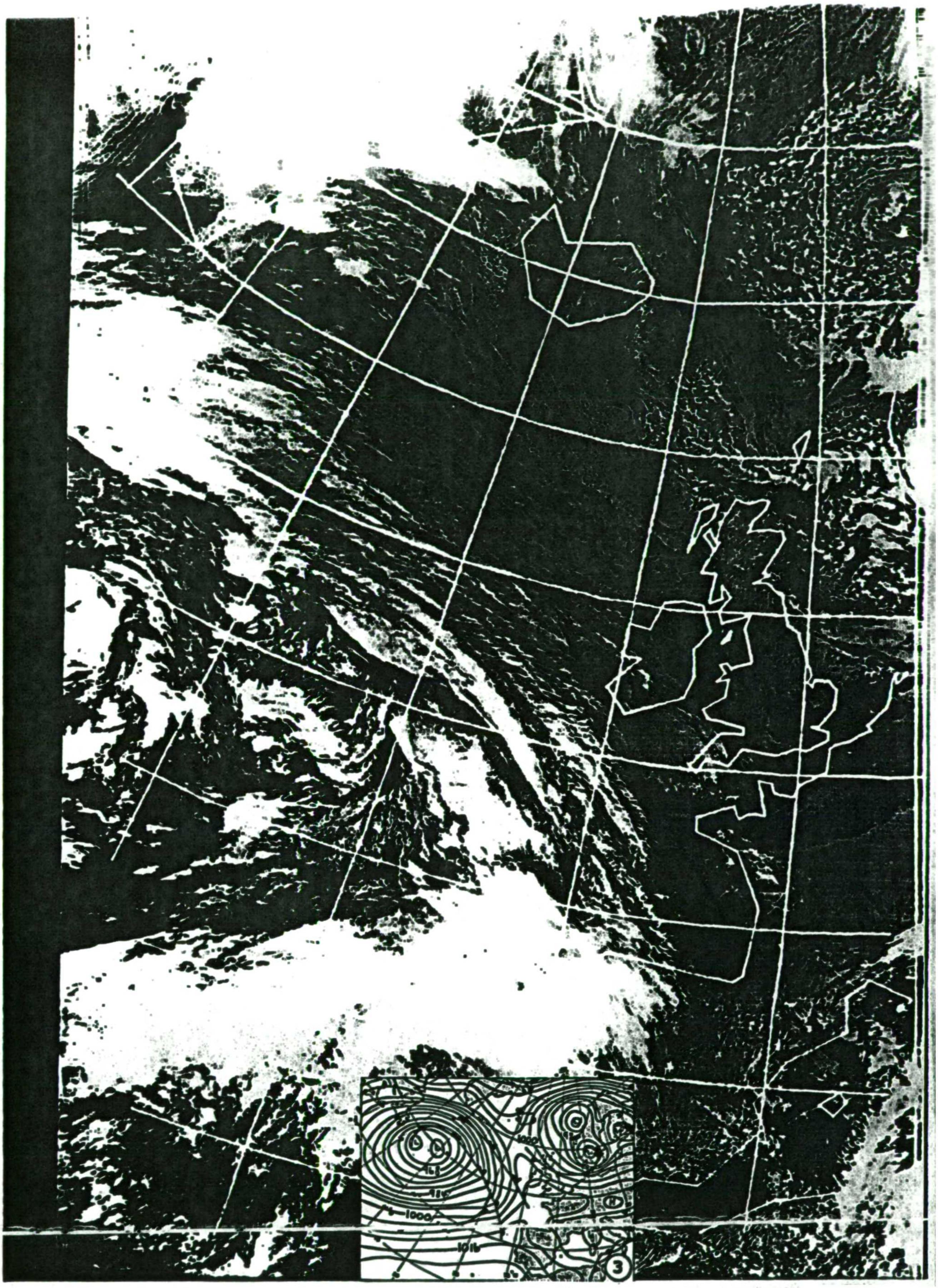
SOLAR TIME	SUN	RN	S (ALL MLY./MIN.)	H	LE	TD	TC (C.)	SUM	RI	TO	T36	Air	T18	Tslab
12.0	256.1	123.1	-30.	-94.	0.	8.00	7.08	1.	-0.00058	8.00	4.10	3.80	4.20	6.40
12.0	255.5	122.2	-29.	-93.	0.	7.53	7.06	0.	-0.00057	7.60	4.00	3.90	4.50	6.40
12.0	253.4	119.3	-27.	-92.	0.	7.27	7.02	0.	-0.00056	7.50	4.10	3.60	4.70	6.40
13.0	250.0	114.6	-25.	-90.	0.	7.11	6.94	0.	-0.00055	7.20	4.10	3.40	4.80	6.10
13.0	245.2	107.9	-22.	-87.	0.	6.97	6.83	0.	-0.00053	7.10	4.10	3.60	5.00	6.00
13.0	238.9	99.5	-17.	-82.	0.	6.83	6.68	0.	-0.00051	7.20	4.20	3.60	5.00	6.10
14.0	231.3	89.3	-12.	-77.	0.	6.66	6.50	0.	-0.00047	6.80	4.10	3.50	5.10	5.60
14.0	222.0	77.3	-7.	-71.	0.	6.47	6.28	0.	-0.00043	6.70	4.20	3.50	5.20	5.60
14.0	210.9	63.7	-1.	-63.	0.	6.25	6.02	0.	-0.00039	6.50	4.30	3.50	5.10	5.40
15.0	198.1	47.1	17.	-64.	0.	5.85	5.46	0.	-0.00040	5.80	4.00	3.20	5.00	5.00
15.0	182.1	30.8	22.	-53.	0.	5.46	5.07	0.	-0.00033	5.70	4.20	3.20	5.20	4.60
15.0	161.6	13.4	28.	-42.	0.	5.07	4.67	0.	-0.00026	5.40	4.20	3.10	5.20	4.30
16.0	132.3	-5.0	34.	-30.	0.	4.67	4.26	0.	-0.00016	5.40	4.40	3.10	5.20	4.20
16.0	75.3	-24.5	41.	-17.	0.	4.25	3.83	0.	-0.00011	5.30	4.40	3.10	5.10	3.70
16.0	0.0	-35.9	43.	-8.	0.	3.87	3.50	0.	-0.00005	4.90	4.50	3.00	5.10	3.60
17.0	0.0	-35.6	39.	-4.	0.	3.61	3.35	0.	-0.00002	4.60	4.40	2.90	5.00	3.30
17.0	0.0	-35.3	36.	-1.	0.	3.43	3.25	0.	0.00000	4.40	4.40	2.60	5.00	3.10
17.0	0.0	-35.2	33.	2.	0.	3.30	3.17	0.	0.00001	4.30	4.50	2.80	4.90	2.90
18.0	0.0	-60.5	90.	-30.	0.	2.49	1.68	0.	-0.00019	3.90	4.40	2.20	4.80	2.30
18.0	0.0	-59.0	78.	-19.	0.	1.89	1.30	0.	-0.00012	3.80	4.50	2.20	4.70	2.20
18.0	0.0	-58.2	70.	-13.	0.	1.49	1.08	0.	-0.00008	3.40	4.50	1.70	4.70	1.50
19.0	0.0	-57.7	66.	-9.	0.	1.21	0.93	0.	-0.00005	3.00	4.50	1.50	4.70	1.00
19.0	0.0	-57.3	62.	-5.	0.	1.01	0.81	0.	-0.00003	2.70	4.60	1.90	4.60	0.80
19.0	0.0	-56.9	59.	-2.	0.	0.86	0.71	0.	-0.00002	2.50	4.70	0.90	4.40	0.50
20.0	0.0	-56.6	56.	0.	0.	0.74	0.63	0.	0.00000	2.10	4.50	0.40	4.30	0.10
20.0	0.0	-56.3	53.	2.	0.	0.65	0.55	0.	0.00001	1.80	4.50	0.70	4.20	0.00
20.0	0.0	-56.0	51.	4.	0.	0.56	0.48	0.	0.00003	1.60	4.60	0.20	4.00	-0.40
21.0	0.0	-55.8	49.	6.	0.	0.49	0.42	0.	0.00004	1.30	4.60	-0.10	3.70	-0.70
21.0	0.0	-55.6	47.	8.	0.	0.42	0.36	0.	0.00005	0.80	4.30	-0.50	3.70	-1.10
21.0	0.0	-55.4	45.	9.	0.	0.36	0.30	0.	0.00006	0.60	4.30	-0.70	3.60	-1.30
22.0	0.0	-55.2	44.	11.	0.	0.31	0.26	0.	0.00007	0.50	4.40	-0.40	3.40	-1.40
22.0	0.0	-55.0	42.	12.	0.	0.26	0.21	0.	0.00008	0.30	4.30	-0.80	3.30	-1.60
22.0	0.0	-54.9	41.	13.	0.	0.21	0.17	0.	0.00008	0.10	4.30	-0.50	3.20	-1.60
23.0	0.0	-54.7	40.	14.	0.	0.17	0.13	0.	0.00009	0.00	4.30	-0.40	3.20	-1.80
23.0	0.0	-54.6	38.	15.	0.	0.13	0.10	0.	0.00010	-0.10	4.40	-0.60	3.10	-1.80
23.0	0.0	-54.5	37.	16.	0.	0.10	0.06	0.	0.00010	-0.20	4.40	-1.20	3.00	-1.90
0.0	0.0	-102.0	107.	-6.	0.	-0.79	-1.67	0.	-0.00004	-0.30	4.30	-1.10	2.90	-2.00
0.0	0.0	-99.5	93.	6.	0.	-1.44	-2.09	0.	0.00005	-0.40	4.20	-1.10	2.80	-2.00
0.0	0.0	-98.1	86.	12.	0.	-1.88	-2.31	0.	0.00009	-0.50	4.10	-1.20	2.70	-2.20
1.0	0.0	-97.2	81.	16.	0.	-2.17	-2.46	0.	0.00013	-0.60	4.10	-1.10	2.50	-2.30
1.0	0.0	-96.5	77.	19.	0.	-2.37	-2.58	0.	0.00015	-0.80	4.10	-1.40	2.20	-2.50
1.0	0.0	-95.9	74.	21.	0.	-2.52	-2.67	0.	0.00017	-0.80	4.00	-1.30	2.10	-2.50
2.0	0.0	-95.4	71.	23.	0.	-2.64	-2.76	0.	0.00019	-1.50	3.80	-2.10	2.00	-3.20
2.0	0.0	-94.9	68.	26.	0.	-2.74	-2.83	0.	0.00021	-1.70	3.80	-2.90	1.90	-3.40
2.0	0.0	-94.5	66.	27.	0.	-2.82	-2.90	0.	0.00022	-1.80	3.70	-2.00	1.70	-3.40
3.0	0.0	-94.1	64.	29.	0.	-2.89	-2.97	0.	0.00023	-1.80	3.60	-2.60	1.60	-3.50
3.0	0.0	-93.7	62.	31.	0.	-2.96	-3.02	0.	0.00025	-1.90	3.60	-2.90	1.50	-3.70
3.0	0.0	-93.4	60.	32.	0.	-3.02	-3.08	0.	0.00026	-2.00	3.50	-2.60	1.40	-3.70
4.0	0.0	-93.1	59.	33.	0.	-3.07	-3.13	0.	0.00027	-2.00	3.50	-2.60	1.30	-3.80
4.0	0.0	-92.8	57.	35.	0.	-3.12	-3.17	0.	0.00028	-2.30	3.40	-3.20	1.20	-4.00
4.0	0.0	-92.6	56.	36.	0.	-3.17	-3.22	0.	0.00029	-2.40	3.30	-3.60	1.30	-4.10
5.0	0.0	-92.3	55.	37.	0.	-3.21	-3.26	0.	0.00030	-2.30	3.30	-1.80	1.00	-3.90
5.0	0.0	-92.1	53.	38.	0.	-3.25	-3.29	0.	0.00031	-2.30	3.20	-1.60	0.90	-3.80
5.0	0.0	-91.9	52.	39.	0.	-3.29	-3.33	0.	0.00031	-2.30	3.20	-2.00	0.90	-3.90
6.0	0.0	-78.6	2.	77.	0.	-2.73	-2.16	0.	0.00062	-2.20	3.10	-2.50	0.90	-4.00
6.0	0.0	-80.1	10.	70.	0.	-2.32	-1.92	0.	0.00057	-2.20	3.20	-2.10	0.90	-3.80
6.0	0.0	-80.7	13.	67.	0.	-2.06	-1.81	0.	0.00054	-2.10	3.20	-1.90	0.80	-3.80
7.0	0.0	-81.1	15.	66.	0.	-1.91	-1.75	0.	0.00053	-2.20	3.00	-1.50	0.80	-3.80
7.0	0.0	-81.3	16.	65.	0.	-1.81	-1.71	0.	0.00052	-2.00	3.00	-1.00	0.80	-3.50
7.0	44.2	-74.8	13.	61.	0.	-1.69	-1.58	0.	0.00049	-1.80	3.00	-1.00	0.70	-3.30
8.0	107.6	-56.9	4.	53.	0.	-1.48	-1.27	0.	0.00043	-1.70	2.90	-0.90	0.60	-2.70
8.0	172.8	-30.7	-10.	40.	0.	-1.13	-0.78	0.	0.00032	-1.40	2.80	-0.80	0.70	-2.90
8.0	236.9	1.6	-25.	23.	0.	-0.64	-0.15	0.	0.00019	-0.80	2.80	-0.20	0.60	-2.50
9.0	298.4	37.4	-42.	3.	0.	-0.02	0.60	0.	0.00003	-0.10	2.80	0.40	0.70	-2.00
9.0	355.5	74.5	-57.	-18.	0.	0.69	1.40	0.	-0.00015	0.60	2.80	0.80	0.80	-1.50
9.0	407.7	111.0	-71.	-41.	0.	1.46	2.24	0.	-0.00032	1.50	2.70	1.90	0.60	-0.50
10.0	464.4	145.5	[illegible]	[illegible]	0.	[illegible]	[illegible]	0.	-0.00050	2.10	2.40	2.00	0.80	0.10
10.0	494.6	176.2	-93.	-84.	0.	3.06	3.85	0.	-0.00067	3.10	2.50	2.70	1.00	1.30
10.0	528.2	202.4	-99.	-104.	0.	3.82	4.58	0.	-0.00082	3.80	2.50	2.50	1.40	2.40
11.0	555.0	223.5	-103.	-121.	0.	4.52	5.22	0.	-0.00095	4.90	2.50	3.20	1.60	3.60
11.0	574.1	238.4	-103.	-135.	0.	5.13	5.75	0.	-0.00106	5.70	2.50	3.70	1.80	4.40
11.0	585.6	246.9	-101.	-146.	0.	5.64	6.16	0.	-0.00115	6.30	2.60	4.30	2.20	3.40

Model Output 02-02-79 Actuals





02-03 FEBRUARY 1979



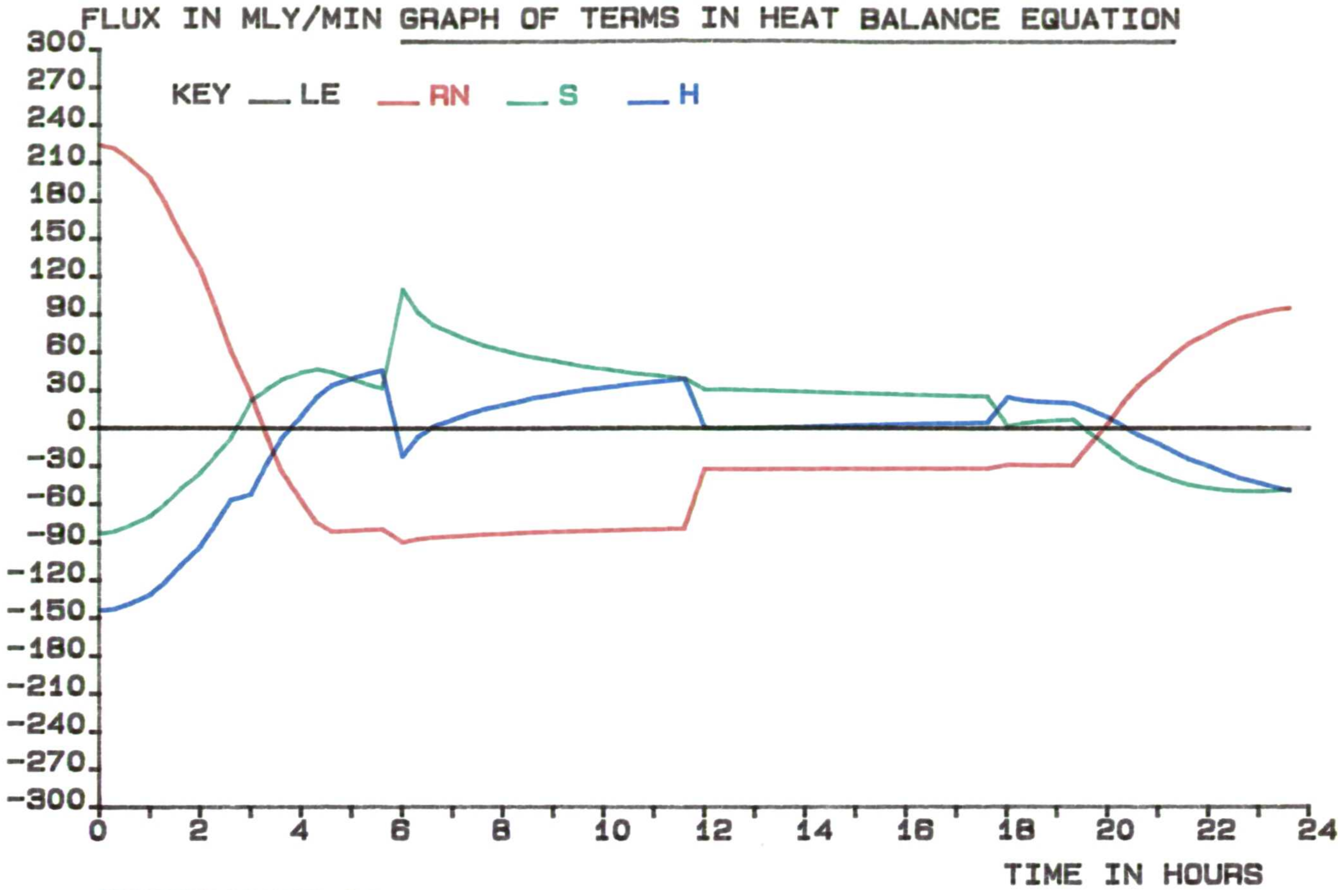
03-02-79

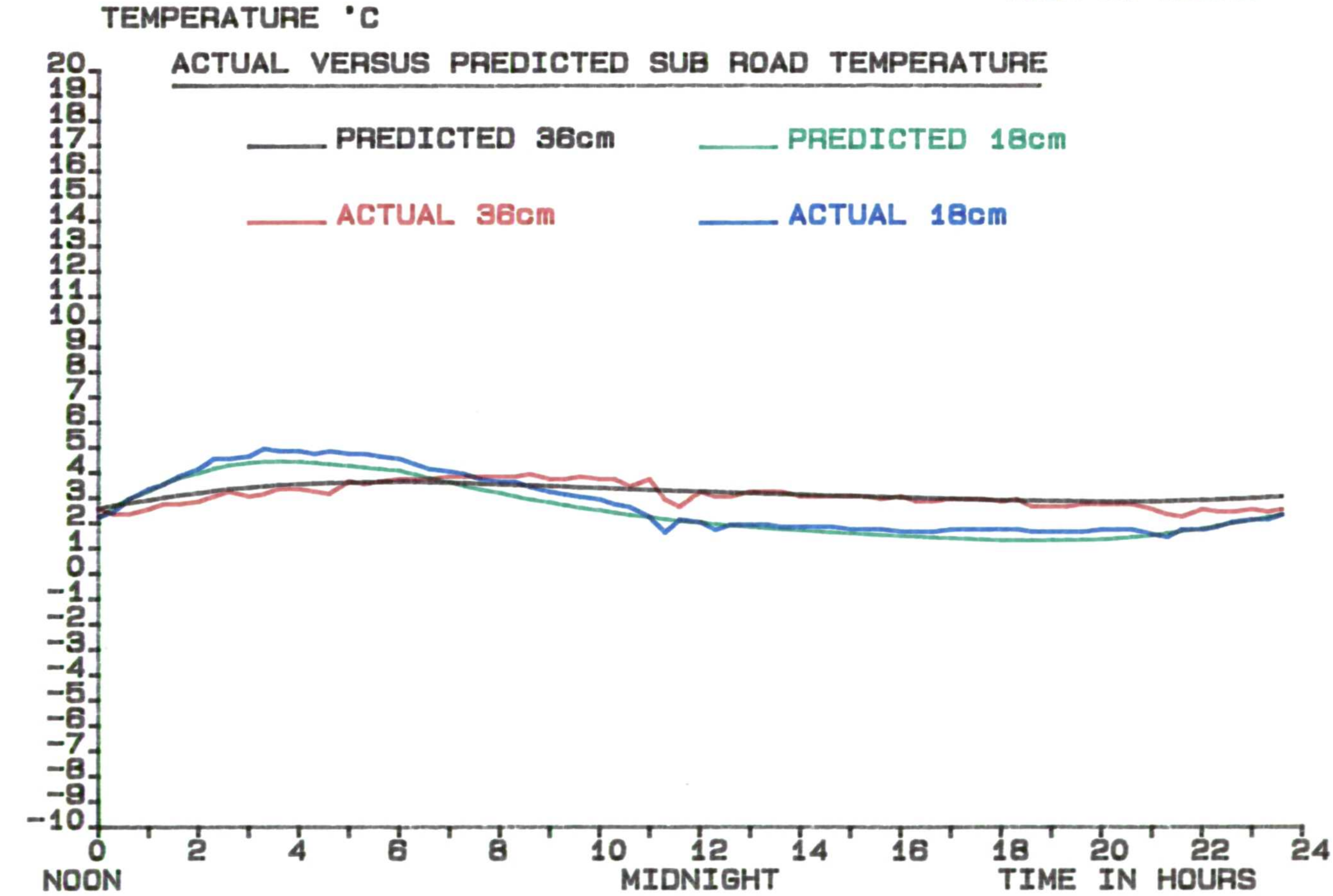
COMPUTED DATA
SAT. VAP. PRESSURE(MB)= 9.03
VAPOUR PRESSURE(MB)= 5.42
REL. HUMIDITY FRACTION = 0.60
APPROX. PRECIP. WATER(MM)= 8.7
ROAD DAMPING DEPTH(CM)= 72.
AIR DAMPING DEPTH(CM)= 2400. 1654.
AIR HEAT TRANSFER COEF.(CGS)= 0.00219 0.00112

DEC	R	T36	T18	TS	UA	D	TIME WET
-16.327	0.986	275.8	275.5	6.8	352. 155.	0.5	0

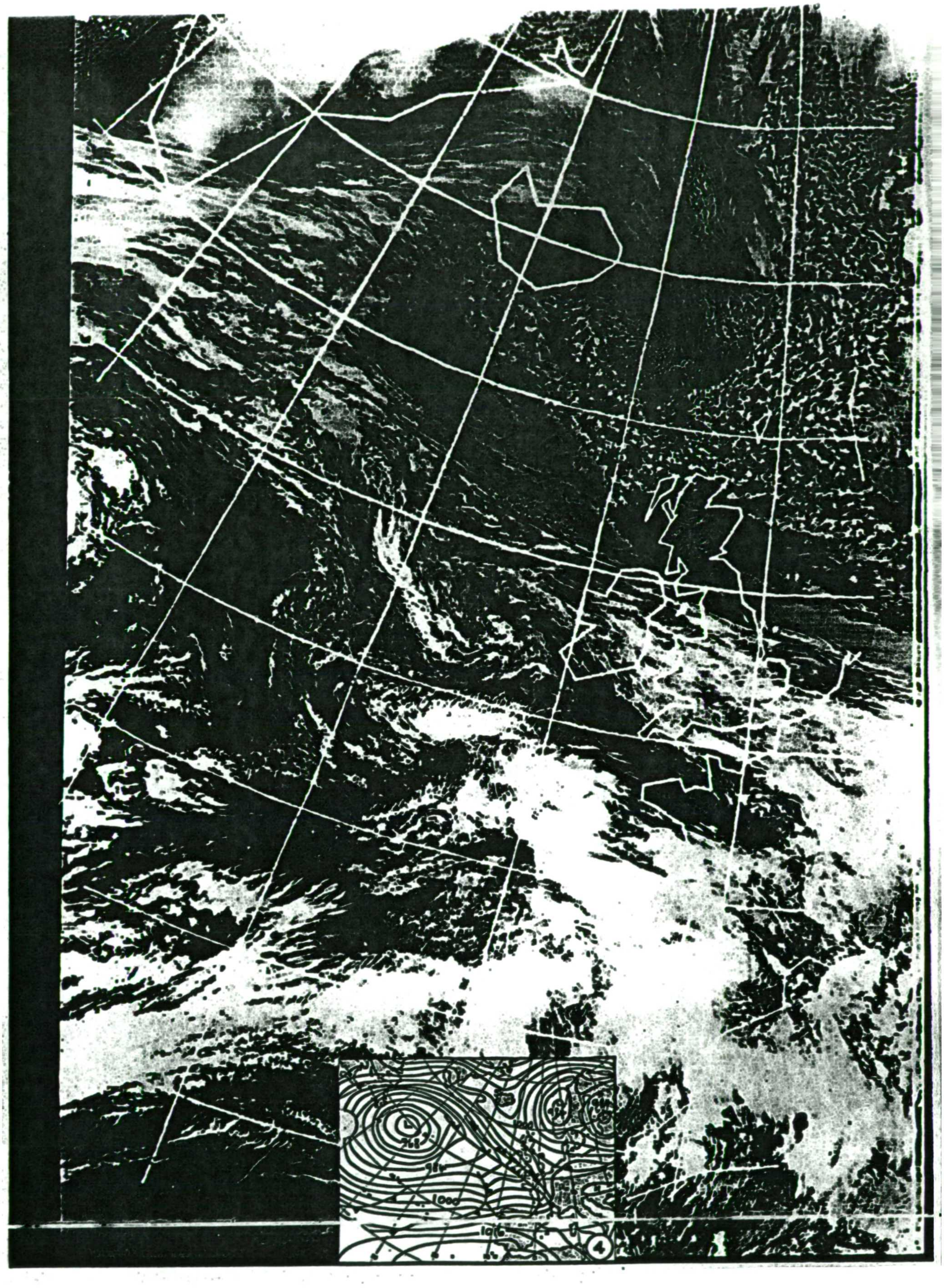
SOLAR TIME	SUN	RN	S	H	LE	TD	TC (C.)	SUN	RI	TO	T36	Air	T18	Tslab
			(ALL MLY./MIN.)											
12.0	529.7	225.1	-82.	-143.	0.	6.80	10.28	1.	-0.00065	6.80	2.60	5.00	2.30	5.50
12.0	526.4	222.1	-81.	-142.	0.	8.52	10.23	0.	-0.00064	7.40	2.40	4.90	2.50	6.20
12.0	516.5	213.2	-76.	-138.	0.	9.31	10.10	0.	-0.00062	7.70	2.40	5.10	3.00	6.80
13.0	500.5	199.0	-69.	-131.	0.	9.60	9.88	0.	-0.00059	8.10	2.60	5.30	3.40	7.30
13.0	478.0	179.2	-59.	-121.	0.	9.58	9.57	0.	-0.00055	8.50	2.80	5.80	3.60	7.60
13.0	449.4	154.8	-47.	-108.	0.	9.37	9.16	0.	-0.00049	8.60	2.80	5.80	3.90	7.70
14.0	415.3	126.8	-35.	-93.	0.	9.03	8.68	0.	-0.00042	8.60	2.90	5.90	4.20	7.90
14.0	375.6	95.5	-21.	-75.	0.	8.58	8.12	0.	-0.00034	8.60	3.10	6.10	4.60	7.90
14.0	330.9	62.5	-7.	-56.	0.	8.05	7.51	0.	-0.00025	8.60	3.30	6.00	4.60	7.50
15.0	281.1	28.3	23.	-51.	0.	7.26	6.47	0.	-0.00024	8.00	3.10	5.90	4.70	7.10
15.0	228.3	-3.5	31.	-28.	0.	6.50	5.74	0.	-0.00013	7.50	3.20	5.80	5.00	5.80
15.0	172.5	-32.6	39.	-8.	0.	5.79	5.08	0.	-0.00003	7.20	3.40	5.70	4.90	4.90
16.0	114.5	-56.6	45.	11.	0.	5.15	4.50	0.	0.00005	6.40	3.40	5.40	4.90	4.30
16.0	53.4	-73.9	47.	25.	0.	4.59	4.03	0.	0.00012	5.00	3.30	4.70	4.80	3.80
16.0	0.0	-81.1	45.	35.	0.	4.16	3.72	0.	0.00016	4.80	3.20	4.00	4.90	3.00
17.0	0.0	-80.2	40.	40.	0.	3.86	3.56	0.	0.00019	4.40	3.70	3.80	4.80	2.20
17.0	0.0	-79.5	36.	44.	0.	3.65	3.44	0.	0.00020	3.90	3.60	3.20	4.80	2.10
17.0	0.0	-79.0	32.	47.	0.	3.50	3.35	0.	0.00022	3.60	3.70	3.00	4.70	1.70
18.0	0.0	-89.6	110.	-21.	0.	2.41	1.32	0.	-0.00010	3.30	3.80	2.30	4.60	1.40
18.0	0.0	-86.9	92.	-6.	0.	1.62	0.83	0.	-0.00003	2.90	3.80	2.40	4.40	0.90
18.0	0.0	-85.4	82.	2.	0.	1.09	0.56	0.	0.00001	2.60	3.80	2.30	4.20	0.60
19.0	0.0	-84.4	76.	8.	0.	0.74	0.39	0.	0.00004	2.40	3.90	2.00	4.10	0.50
19.0	0.0	-83.6	70.	12.	0.	0.49	0.25	0.	0.00006	2.20	3.90	2.20	4.00	0.40
19.0	0.0	-83.0	66.	16.	0.	0.31	0.13	0.	0.00007	2.00	3.90	0.60	3.80	0.10
20.0	0.0	-82.5	62.	19.	0.	0.17	0.03	0.	0.00009	1.70	3.90	0.90	3.70	-0.30
20.0	0.0	-82.0	59.	22.	0.	0.06	-0.06	0.	0.00010	1.50	3.90	0.20	3.70	-0.50
20.0	0.0	-81.5	57.	25.	0.	-0.05	-0.15	0.	0.00012	1.20	4.00	-0.20	3.50	-1.00
21.0	0.0	-81.1	54.	27.	0.	-0.14	-0.22	0.	0.00013	0.90	3.80	-0.80	3.30	-1.00
21.0	0.0	-80.7	51.	29.	0.	-0.21	-0.29	0.	0.00014	0.70	3.80	-0.10	3.20	-1.20
21.0	0.0	-80.4	49.	31.	0.	-0.28	-0.35	0.	0.00015	0.60	3.90	-0.80	3.10	-1.30
22.0	0.0	-80.1	47.	33.	0.	-0.34	-0.40	0.	0.00015	0.20	3.80	-0.80	3.00	-1.70
22.0	0.0	-79.8	45.	34.	0.	-0.40	-0.45	0.	0.00016	0.30	3.80	0.90	2.80	-1.40
22.0	0.0	-79.6	44.	36.	0.	-0.45	-0.50	0.	0.00017	0.00	3.50	1.20	2.70	-1.80
23.0	0.0	-79.3	42.	37.	0.	-0.49	-0.54	0.	0.00017	0.00	3.80	-1.50	2.30	-1.80
23.0	0.0	-79.1	41.	38.	0.	-0.54	-0.58	0.	0.00018	-0.80	3.00	-1.80	1.70	-2.40
23.0	0.0	-78.9	39.	39.	0.	-0.58	-0.61	0.	0.00018	-0.80	2.70	-1.40	2.20	-2.60
0.0	0.0	-31.9	31.	1.	0.	-0.52	-0.47	0.	0.00002	0.00	3.30	-0.80	2.10	-1.60
0.0	0.0	-31.9	31.	0.	0.	-0.49	-0.46	0.	0.00002	-0.10	3.10	-0.90	1.80	-1.70
0.0	0.0	-31.9	31.	1.	0.	-0.48	-0.47	0.	0.00002	-0.10	3.10	-1.20	2.00	-1.60
1.0	0.0	-31.9	31.	1.	0.	-0.48	-0.49	0.	0.00004	0.20	3.30	-0.90	2.00	-1.30
1.0	0.0	-31.8	30.	1.	0.	-0.50	-0.51	0.	0.00005	0.20	3.30	-0.90	2.00	-1.30
1.0	0.0	-31.8	30.	2.	0.	-0.51	-0.53	0.	0.00007	0.30	3.30	-0.50	1.90	-1.20
2.0	0.0	-31.8	29.	2.	0.	-0.53	-0.55	0.	0.00008	0.20	3.10	-0.70	1.90	-1.20
2.0	0.0	-31.7	29.	2.	0.	-0.56	-0.58	0.	0.00010	0.30	3.10	-0.60	1.90	-1.20
2.0	0.0	-31.7	29.	3.	0.	-0.58	-0.60	0.	0.00011	0.30	3.10	-0.70	1.90	-1.00
3.0	0.0	-31.6	28.	3.	0.	-0.60	-0.62	0.	0.00013	0.30	3.10	-0.80	1.80	-1.10
3.0	0.0	-31.6	28.	3.	0.	-0.62	-0.64	0.	0.00014	0.30	3.10	-0.80	1.80	-1.00
3.0	0.0	-31.5	28.	4.	0.	-0.64	-0.66	0.	0.00016	0.30	3.00	-0.60	1.80	-1.00
4.0	0.0	-31.5	27.	4.	0.	-0.66	-0.68	0.	0.00017	0.40	3.10	-0.50	1.70	-1.00
4.0	0.0	-31.5	27.	4.	0.	-0.67	-0.69	0.	0.00018	0.20	2.90	-0.60	1.70	-1.10
4.0	0.0	-31.4	27.	4.	0.	-0.69	-0.71	0.	0.00019	0.30	2.90	-0.50	1.70	-0.90
5.0	0.0	-31.4	26.	5.	0.	-0.71	-0.73	0.	0.00021	0.40	3.00	-0.30	1.80	-0.90
5.0	0.0	-31.4	26.	5.	0.	-0.73	-0.74	0.	0.00022	0.40	3.00	-0.30	1.80	-0.80
5.0	0.0	-31.3	26.	5.	0.	-0.74	-0.76	0.	0.00023	0.50	3.00	0.10	1.80	-0.50
6.0	0.0	-28.1	2.	25.	0.	-0.48	-0.21	0.	0.00110	0.50	2.90	0.10	1.60	-0.60
6.0	0.0	-28.4	5.	23.	0.	-0.27	-0.06	0.	0.00100	0.80	3.00	0.40	1.80	-0.40
6.0	0.0	-28.6	6.	22.	0.	-0.13	0.02	0.	0.00095	0.60	2.70	0.20	1.70	-0.60
7.0	0.0	-28.7	7.	21.	0.	-0.03	0.06	0.	0.00091	0.70	2.70	0.20	1.70	-0.50
7.0	0.0	-28.8	8.	20.	0.	0.03	0.09	0.	0.00089	0.80	2.70	0.40	1.70	-0.30
7.0	66.4	-14.3	-2.	16.	0.	0.20	0.37	0.	0.00070	1.00	2.80	0.60	1.70	-0.10
8.0	132.7	4.1	-14.	9.	0.	0.50	0.79	0.	0.00040	1.00	2.80	0.60	1.80	0.00
8.0	154.4	20.2	-23.	2.	0.	0.86	1.23	0.	0.00010	1.30	2.80	0.90	1.80	0.20
8.0	168.0	34.5	-30.	-5.	0.	1.26	1.66	0.	-0.00021	1.40	2.80	1.00	1.80	0.50
9.0	177.7	47.2	-36.	-12.	0.	1.67	2.08	0.	-0.00050	1.60	2.60	0.90	1.60	0.60
9.0	185.0	58.3	-41.	-18.	0.	2.07	2.47	0.	-0.00077	1.60	2.40	0.70	1.50	[illegible]
9.0	190.7	67.8	-44.	-24.	0.	2.45	2.84	0.	-0.00103	1.90	2.30	1.00	1.80	1.00
10.0	195.2	75.9	-47.	-29.	0.	[illegible]	[illegible]	0.	-0.00126	2.50	2.60	1.70	1.80	1.50
[illegible]	[illegible]	[illegible]	-48.	-34.	0.	3.14	3.48	0.	-0.00147	2.70	2.50	1.80	1.90	1.80
10.0	201.7	87.8	-49.	-39.	0.	3.45	3.75	0.	-0.00166	3.10	2.50	2.40	2.10	2.20
11.0	203.8	91.8	-49.	-43.	0.	3.72	3.99	0.	-0.00183	3.40	2.60	2.80	2.20	2.60
11.0	205.3	94.5	-49.	-46.	0.	3.96	4.19	0.	-0.00197	3.50	2.50	2.90	2.20	2.60
11.0	206.1	96.8	-47.	-49.	0.	4.16	4.37	0.	-0.00209	4.00	2.60	3.10	2.40	3.10

Model Output 03-02-79 Actuals





03-04 FEBRUARY 1979



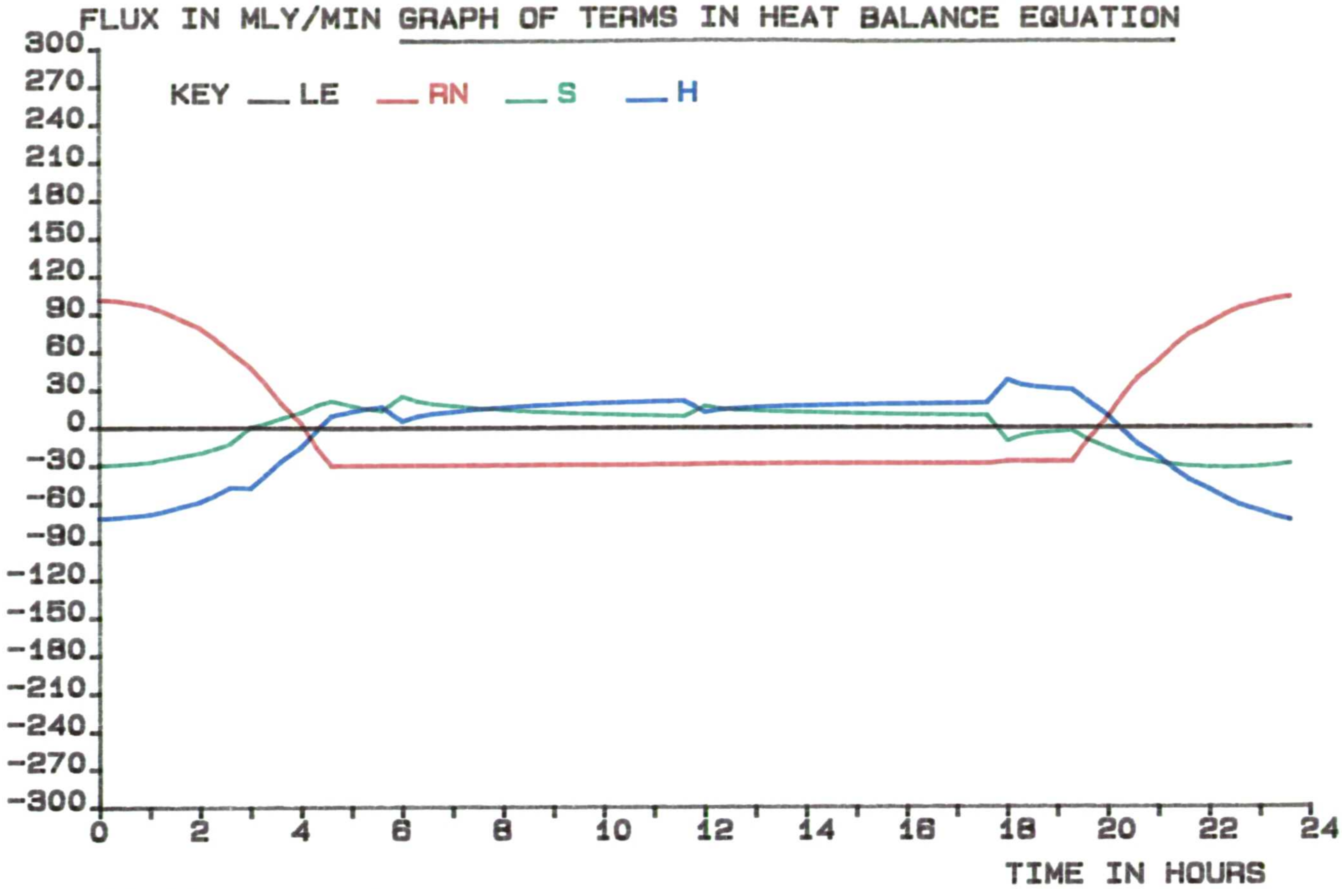
04-02-79

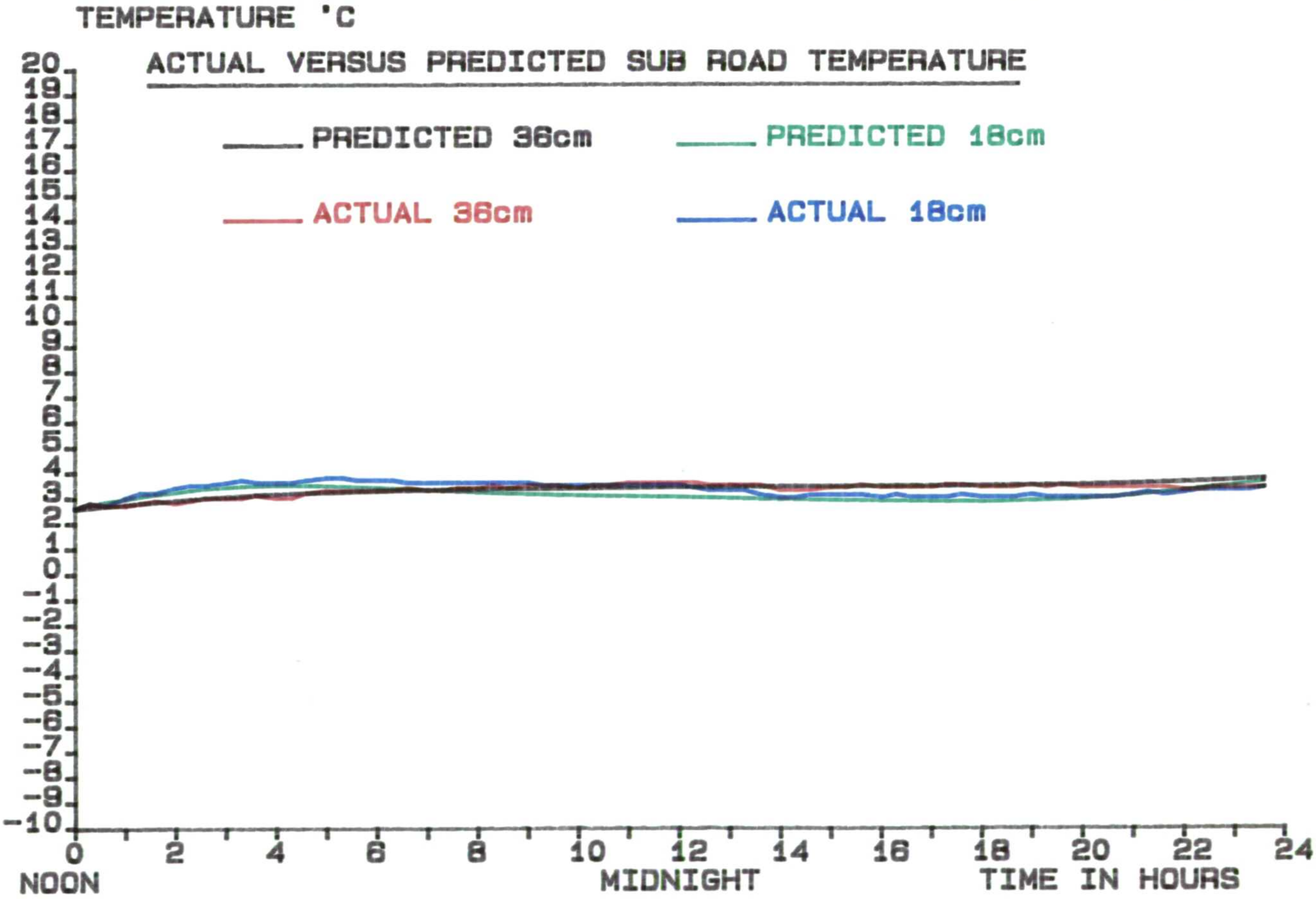
[illegible]
SAT. VAP. PRESSURE(MB)= 7,90
VAPOUR PRESSURE(MB)= 6,40
REL. HUMIDITY FRACTION = 0.81
APPROX. PRECIP. WATER(MM)= 10.2
ROAD DAMPING DEPTH(CM)= 72.
AIR DAMPING DEPTH(CM)= 2899. 2872.
AIR HEAT TRANSFER COEF.(CGS)= 0.00308 0.00302

DEC	R	T36	T18	TS	UA	D	TIME WET
-16.027	0.986	275.8	275.8	4.3	533. 522.	0.5	0

SOLAR TIME	SUN	RN	S	H	LE	TD	TC	SUN	RI	TO	T36	Air	T18	Tslab
		(ALL MLY./MIN.)					(C.)							
12.0	206.5	100.8	-30.	-72.	0.	4.30	5.51	1.	-0.00011	4.30	2.60	3.30	2.60	3.50
12.0	206.2	100.2	-30.	-71.	0.	4.90	5.50	0.	-0.00011	4.60	2.80	3.60	2.80	3.90
12.0	205.3	98.4	-29.	-70.	0.	5.19	5.47	0.	-0.00010	5.20	2.70	3.60	2.70	4.60
13.0	203.9	95.4	-27.	-69.	0.	5.31	5.44	0.	-0.00010	5.20	2.70	3.70	3.00	4.60
13.0	201.7	91.0	-26.	-66.	0.	5.35	5.38	0.	-0.00010	5.30	2.80	3.70	3.20	4.20
13.0	198.9	85.3	-23.	-63.	0.	5.33	5.31	0.	-0.00009	5.00	2.90	3.80	3.20	4.20
14.0	195.4	78.3	-20.	-59.	0.	5.27	5.21	0.	-0.00009	5.00	2.80	3.70	3.40	4.20
14.0	190.8	69.9	-17.	-54.	0.	5.19	5.10	0.	-0.00008	5.00	2.90	3.70	3.50	4.20
14.0	185.1	59.9	-13.	-47.	0.	5.07	4.96	0.	-0.00007	4.90	3.00	3.60	3.50	3.60
15.0	177.9	47.0	0.	-48.	0.	4.82	4.57	0.	-0.00007	4.70	3.00	3.50	3.60	3.70
15.0	168.4	34.0	3.	-38.	0.	4.58	4.34	0.	-0.00006	4.80	3.00	3.50	3.70	3.60
15.0	154.9	19.4	7.	-27.	0.	4.34	4.10	0.	-0.00004	5.00	3.10	3.50	3.60	3.60
16.0	133.5	3.0	12.	-15.	0.	4.09	3.84	0.	-0.00002	4.40	3.00	3.30	3.60	3.40
16.0	88.8	-15.6	17.	-3.	0.	3.82	3.55	0.	0.00000	4.30	3.00	3.10	3.60	3.10
16.0	0.0	-30.7	21.	9.	0.	3.55	3.28	0.	0.00001	4.20	3.20	3.00	3.70	3.00
17.0	0.0	-30.5	17.	13.	0.	3.38	3.20	0.	0.00002	4.20	3.30	3.10	3.60	2.60
17.0	0.0	-30.4	15.	15.	0.	3.26	3.15	0.	0.00002	3.90	3.30	2.80	3.80	2.60
17.0	0.0	-30.3	13.	17.	0.	3.19	3.12	0.	0.00002	3.70	3.30	2.70	3.70	2.30
18.0	0.0	-30.5	25.	5.	0.	2.98	2.77	0.	0.00001	3.60	3.30	2.80	3.70	2.30
18.0	0.0	-30.3	21.	9.	0.	2.84	2.69	0.	0.00001	3.60	3.30	2.80	3.70	2.30
18.0	0.0	-30.2	18.	11.	0.	2.74	2.64	0.	0.00002	3.70	3.40	2.90	3.60	2.30
19.0	0.0	-30.1	17.	13.	0.	2.67	2.61	0.	0.00002	3.80	3.30	2.80	3.60	2.30
19.0	0.0	-30.1	16.	14.	0.	2.63	2.58	0.	0.00002	3.40	3.30	2.70	3.60	2.20
19.0	0.0	-30.0	15.	15.	0.	2.59	2.56	0.	0.00002	3.50	3.40	2.70	3.60	2.20
20.0	0.0	-30.0	14.	16.	0.	2.56	2.54	0.	0.00002	3.50	3.40	2.70	3.60	2.20
20.0	0.0	-29.9	13.	16.	0.	2.54	2.52	0.	0.00002	3.50	3.50	2.70	3.60	2.20
20.0	0.0	-29.9	12.	17.	0.	2.52	2.50	0.	0.00003	3.40	3.40	2.60	3.60	2.10
21.0	0.0	-29.9	11.	18.	0.	2.51	2.49	0.	0.00003	3.40	3.50	2.60	3.60	2.00
21.0	0.0	-29.9	11.	18.	0.	2.49	2.48	0.	0.00003	3.30	3.50	2.60	3.50	2.00
21.0	0.0	-29.8	10.	19.	0.	2.48	2.47	0.	0.00003	3.20	3.50	2.40	3.50	1.90
22.0	0.0	-29.8	10.	19.	0.	2.47	2.46	0.	0.00003	3.10	3.40	2.30	3.50	1.80
22.0	0.0	-29.8	10.	20.	0.	2.46	2.45	0.	0.00003	3.10	3.50	2.30	3.50	1.90
22.0	0.0	-29.8	9.	20.	0.	2.45	2.44	0.	0.00003	3.20	3.50	2.30	3.50	1.90
23.0	0.0	-29.8	9.	20.	0.	2.44	2.43	0.	0.00003	3.10	3.60	2.30	3.50	1.70
23.0	0.0	-29.7	9.	20.	0.	2.44	2.43	0.	0.00003	3.00	3.60	2.20	3.50	1.70
23.0	0.0	-29.7	8.	21.	0.	2.43	2.42	0.	0.00003	2.90	3.60	2.20	3.50	1.70
0.0	0.0	-29.2	17.	12.	0.	2.32	2.21	0.	0.00002	2.80	3.60	2.20	3.50	1.60
0.0	0.0	-29.1	14.	14.	0.	2.25	2.17	0.	0.00002	2.80	3.60	2.30	3.40	1.60
0.0	0.0	-29.1	13.	15.	0.	2.20	2.15	0.	0.00002	2.70	3.50	2.30	3.30	1.50
1.0	0.0	-29.1	13.	16.	0.	2.16	2.13	0.	0.00002	2.60	3.50	2.20	3.30	1.50
1.0	0.0	-29.0	12.	16.	0.	2.14	2.12	0.	0.00003	2.70	3.50	2.20	3.30	1.60
1.0	0.0	-29.0	12.	16.	0.	2.13	2.11	0.	0.00003	2.70	3.50	2.40	3.10	1.70
2.0	0.0	-29.0	11.	17.	0.	2.11	2.10	0.	0.00003	2.40	3.30	2.10	3.00	1.60
2.0	0.0	-29.0	11.	17.	0.	2.10	2.09	0.	0.00003	2.40	3.30	2.00	3.00	1.50
2.0	0.0	-29.0	11.	17.	0.	2.10	2.09	0.	0.00003	2.30	3.30	2.00	3.10	1.40
3.0	0.0	-29.0	10.	18.	0.	2.09	2.08	0.	0.00003	2.50	3.40	2.10	3.10	1.50
3.0	0.0	-28.9	10.	18.	0.	2.08	2.08	0.	0.00003	2.40	3.40	2.00	3.10	1.50
3.0	0.0	-28.9	10.	18.	0.	2.08	2.07	0.	0.00003	2.50	3.50	2.10	3.10	1.50
4.0	0.0	-28.9	10.	18.	0.	2.07	2.07	0.	0.00003	2.40	3.40	2.10	3.00	1.50
4.0	0.0	-28.9	10.	19.	0.	2.07	2.06	0.	0.00003	2.40	3.40	2.10	3.10	1.50
4.0	0.0	-28.9	9.	19.	0.	2.06	2.06	0.	0.00003	2.40	3.40	2.20	3.00	1.40
5.0	0.0	-28.9	9.	19.	0.	2.06	2.06	0.	0.00003	2.40	3.40	2.20	3.00	1.30
5.0	0.0	-28.9	9.	19.	0.	2.06	2.05	0.	0.00003	2.40	3.50	2.40	3.00	1.40
5.0	0.0	-28.9	9.	19.	0.	2.05	2.05	0.	0.00003	2.50	3.50	2.40	3.10	1.40
6.0	0.0	-27.0	-11.	37.	0.	2.29	2.53	0.	0.00006	2.40	3.40	2.40	3.00	1.20
6.0	0.0	-27.2	-7.	33.	0.	2.46	2.63	0.	0.00005	2.50	3.40	2.30	3.00	1.20
6.0	0.0	-27.3	-5.	31.	0.	2.56	2.67	0.	0.00005	2.50	3.40	2.20	3.00	1.10
7.0	0.0	-27.3	-4.	30.	0.	2.63	2.69	0.	0.00005	2.50	3.50	2.20	3.10	1.10
7.0	0.0	-27.4	-3.	29.	0.	2.67	2.71	0.	0.00005	2.50	3.40	2.00	3.00	1.20
7.0	92.7	-11.0	-10.	20.	0.	2.79	2.92	0.	0.00003	2.50	3.50	2.00	3.00	0.90
8.0	135.3	7.6	-17.	9.	0.	2.99	3.19	0.	0.00001	2.50	3.40	2.20	3.00	0.80
8.0	156.1	24.0	-22.	-3.	0.	3.22	3.45	0.	0.00000	2.80	3.40	2.40	3.00	1.20
8.0	169.2	38.6	-26.	-14.	0.	3.46	3.71	0.	-0.00002	3.10	3.40	2.80	3.00	1.60
9.0	178.6	51.6	-28.	-24.	0.	3.70	3.94	0.	-0.00004	3.30	3.40	3.00	3.10	2.00
9.0	185.8	63.0	-30.	-34.	0.	3.93	4.16	0.	-0.00005	3.70	3.40	3.10	3.20	2.50
9.0	191.4	72.8	-32.	-42.	0.	4.14	4.35	0.	-0.00007	4.00	3.40	3.40	3.10	2.90
10.0	195.9	81.2	-32.	-50.	0.	4.33	4.53	0.	-0.00008	4.30	3.30	3.30	3.20	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.	-0.00009	5.20	3.30	4.10	3.30	4.30
10.0	202.2	93.6	-32.	-62.	0.	4.66	4.81	0.	-0.00010	6.60	3.40	4.70	3.30	6.40
11.0	204.4	97.8	-32.	-67.	0.	4.79	4.92	0.	-0.00010	6.70	3.40	4.70	3.30	6.80
11.0	205.8	100.8	-31.	-71.	0.	4.90	5.01	0.	-0.00011	6.80	3.40	4.70	3.30	[illegible]
11.0	206.7	102.5	-29.	-74.	0.	4.99	5.08	0.	-0.00012	6.90	3.40	4.80	3.40	7.00

Model Output 04-02-79 Actuals





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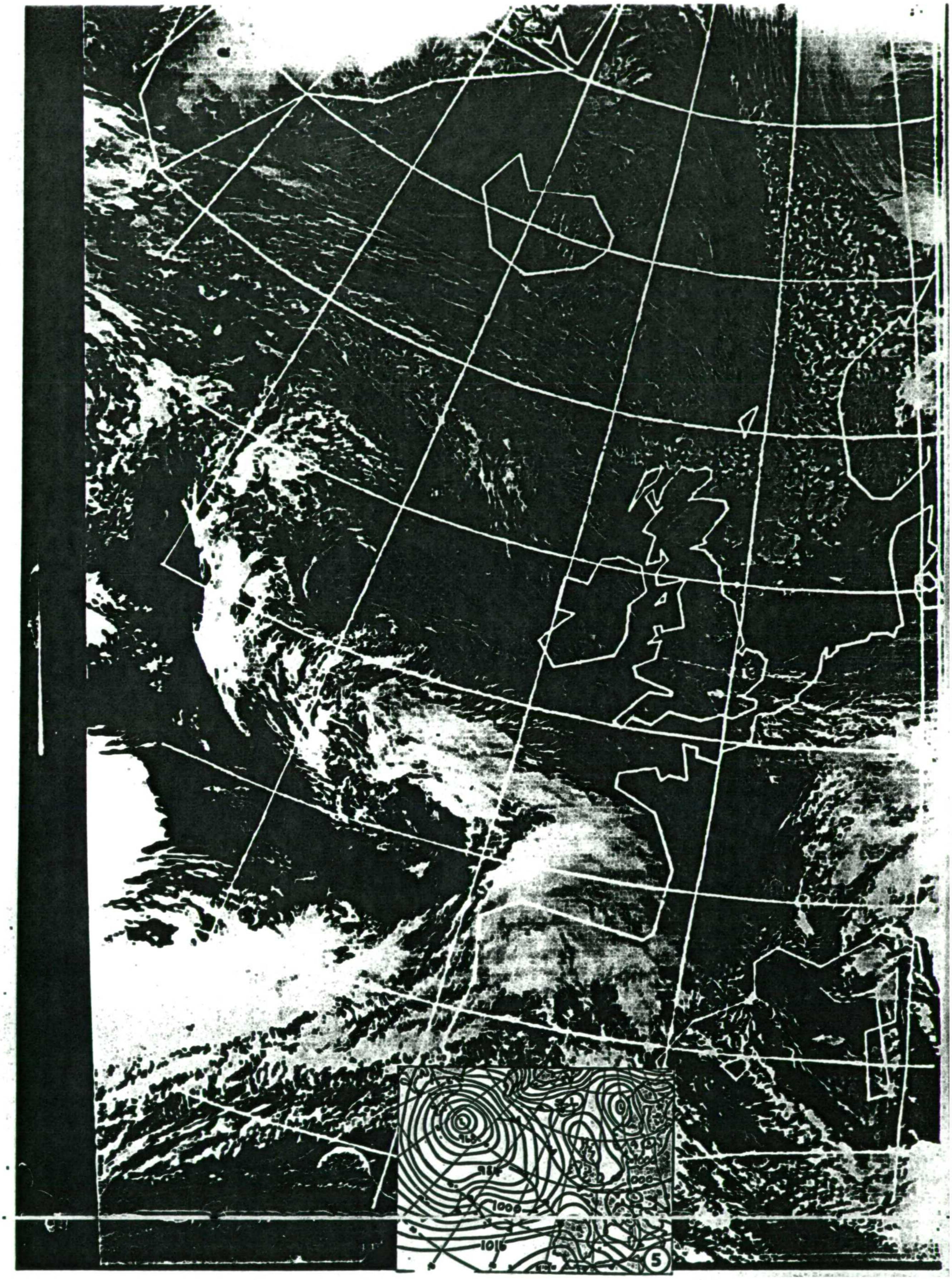


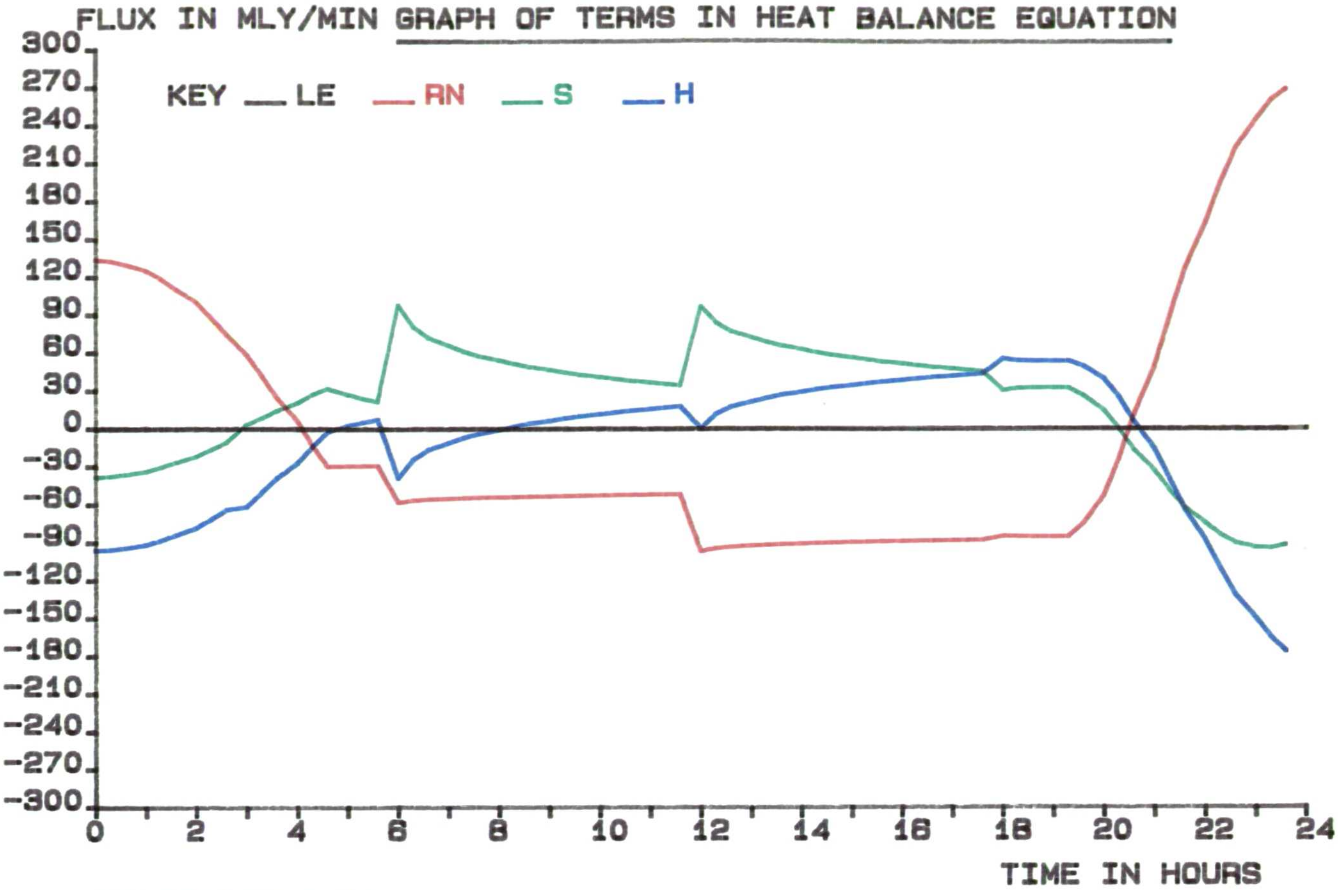
05-02-79

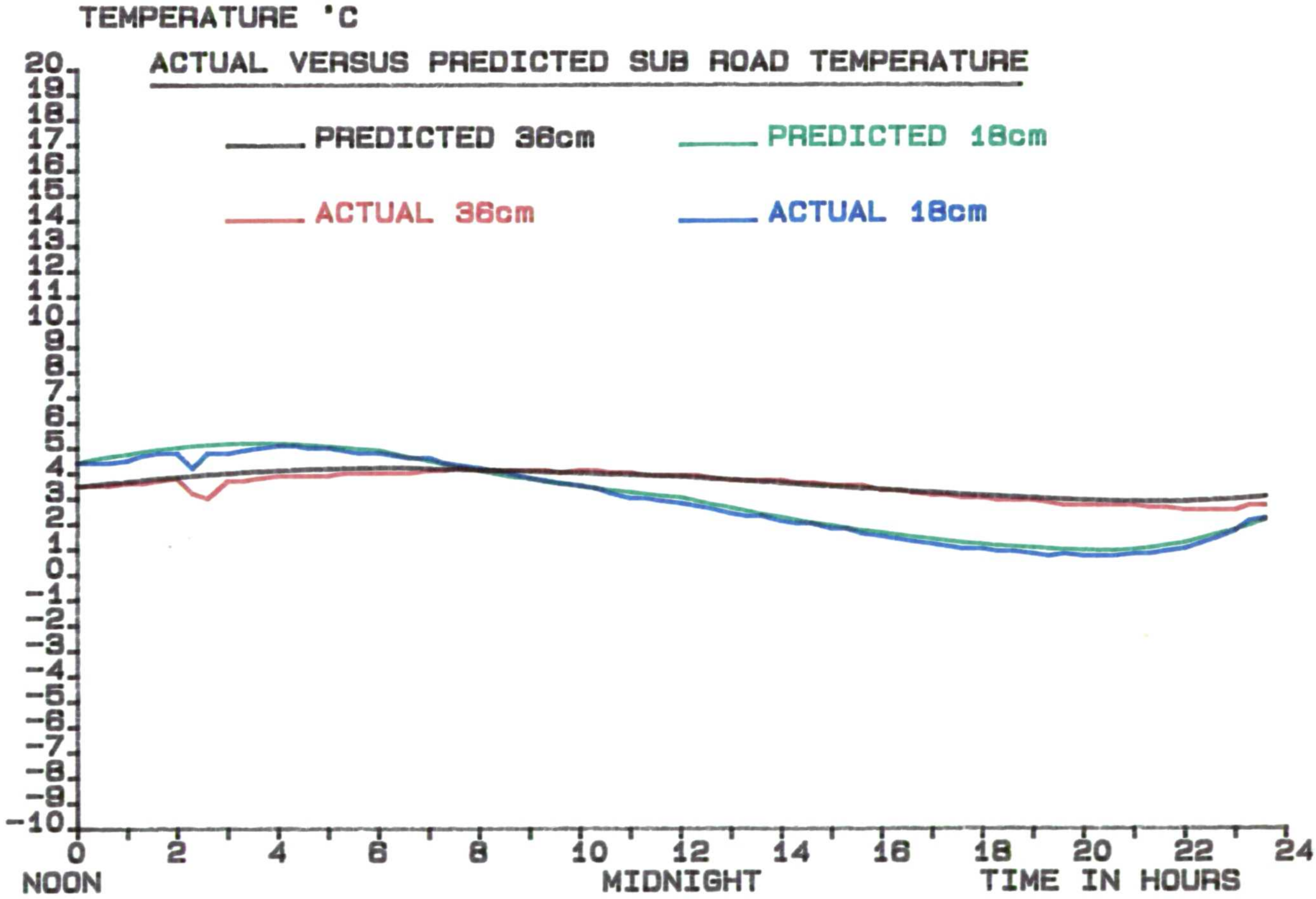
COMPUTED DATA
SAT. VAP. PRESSURE(MB)= 8.66
VAPOUR PRESSURE(MB)= 7.10
REL. HUMIDITY FRACTION = 0.82
APPROX. PRECIP. WATER(MM)= 11.3
ROAD DAMPING DEPTH(CM)= 72.
AIR DAMPING DEPTH(CM)= 2427. 2333.
AIR HEAT TRANSFER COEF.(CGS)= 0.00223 0.00208

DEC	R	T36	T18	TS	UA	D	TIME WET
-15.722	0.986	276.7	277.6	7.0	361. 331.	0.5	0

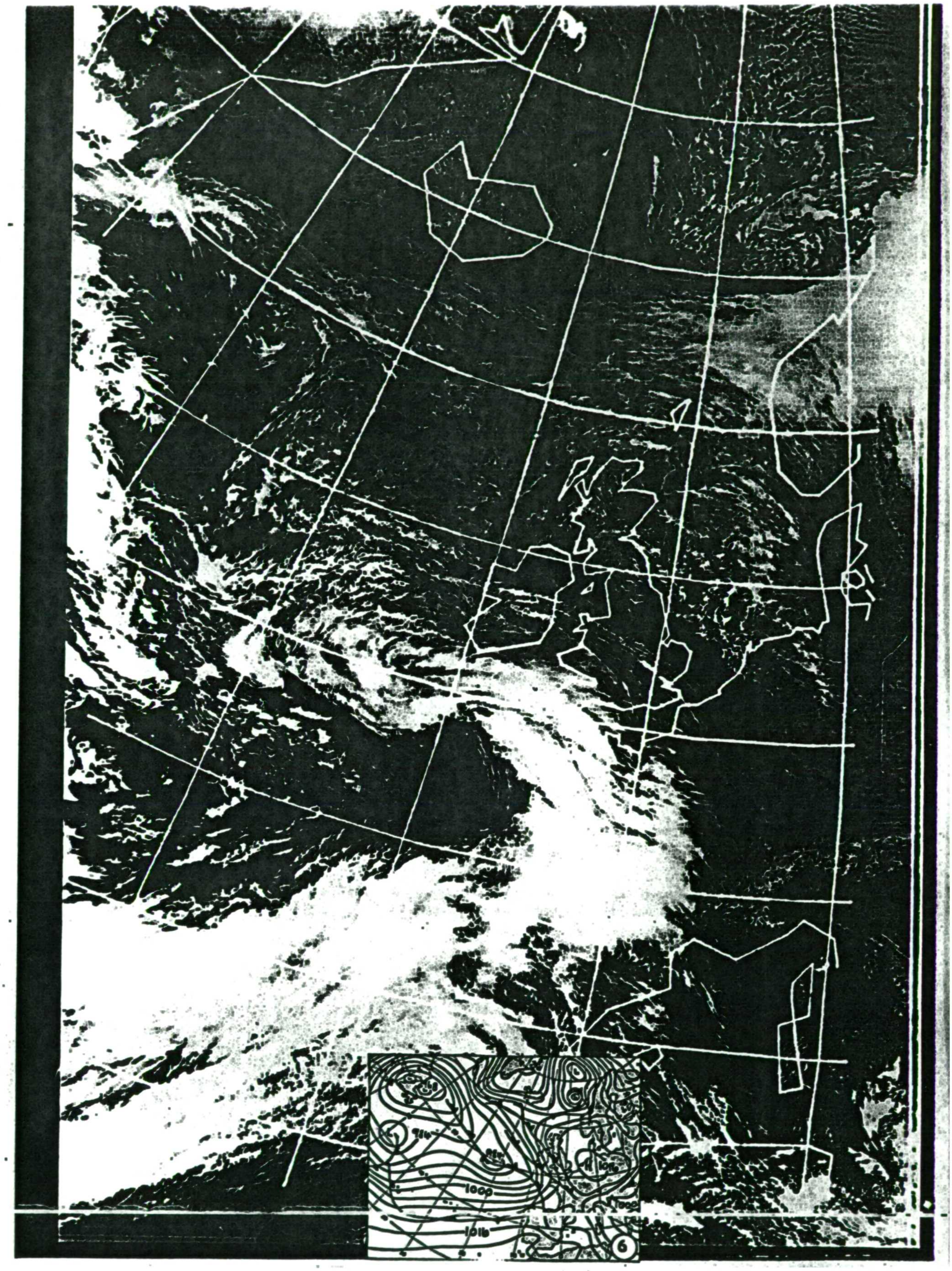
SOLAR TIME	SUN	RN	S	H	LE	TD	TC	SUM	RI	TO	T36	Air	T18	Tsla
			(ALL MLY./MIN.)				(C.)							
12.0	257.8	133.2	-38.	-96.	0.	7.00	8.12	1.	-0.00041	7.00	3.50	4.80	4.40	6.00
12.0	257.1	132.3	-38.	-95.	0.	7.55	8.10	0.	-0.00040	7.10	3.50	4.90	4.40	6.00
12.0	255.1	129.4	-36.	-94.	0.	7.80	8.06	0.	-0.00040	7.10	3.50	4.90	4.40	6.00
13.0	251.8	124.8	-34.	-92.	0.	7.89	7.99	0.	-0.00039	7.10	3.60	5.00	4.50	6.10
13.0	247.1	118.2	-31.	-88.	0.	7.89	7.88	0.	-0.00037	7.60	3.60	5.20	4.70	6.40
13.0	241.0	109.8	-27.	-84.	0.	7.82	7.75	0.	-0.00036	7.10	3.70	5.10	4.80	6.00
14.0	233.5	99.7	-22.	-78.	0.	7.70	7.58	0.	-0.00033	7.00	3.80	5.20	4.80	5.90
14.0	224.5	87.8	-17.	-72.	0.	7.53	7.37	0.	-0.00031	6.30	3.20	4.40	4.20	5.10
14.0	213.8	74.3	-11.	-64.	0.	7.33	7.13	0.	-0.00027	6.00	3.00	4.20	4.80	4.90
15.0	201.5	58.2	3.	-62.	0.	7.00	6.67	0.	-0.00026	6.90	3.70	5.40	4.80	6.10
15.0	186.4	41.9	8.	-51.	0.	6.66	6.32	0.	-0.00022	7.30	3.70	5.60	4.90	6.40
15.0	167.4	24.5	14.	-39.	0.	6.31	5.96	0.	-0.00017	6.70	3.80	5.00	5.00	5.10
16.0	141.4	6.2	20.	-27.	0.	5.95	5.59	0.	-0.00012	6.10	3.90	4.30	5.10	4.30
16.0	95.8	-13.3	27.	-14.	0.	5.57	5.19	0.	-0.00006	5.60	3.90	4.20	5.10	3.90
16.0	0.0	-30.1	32.	-2.	0.	5.19	4.82	0.	-0.00001	5.40	3.90	3.90	5.00	3.80
17.0	0.0	-29.8	27.	2.	0.	4.93	4.67	0.	0.00001	5.10	3.90	4.30	5.00	3.60
17.0	0.0	-29.6	24.	5.	0.	4.76	4.58	0.	0.00002	4.90	4.00	3.80	4.90	3.10
17.0	0.0	-29.5	21.	7.	0.	4.63	4.51	0.	0.00003	5.10	4.00	3.90	4.80	3.40
18.0	0.0	-58.6	97.	-39.	0.	3.60	2.57	0.	-0.00017	4.40	4.00	3.40	4.80	2.60
18.0	0.0	-56.9	81.	-25.	0.	2.85	2.11	0.	-0.00011	3.80	4.00	2.90	4.70	2.10
18.0	0.0	-56.0	72.	-17.	0.	2.36	1.86	0.	-0.00007	3.40	4.00	2.40	4.60	1.50
19.0	0.0	-55.3	66.	-11.	0.	2.03	1.69	0.	-0.00005	3.10	4.10	2.10	4.60	1.10
19.0	0.0	-54.9	61.	-7.	0.	1.80	1.57	0.	-0.00003	2.80	4.10	1.80	4.40	0.80
19.0	0.0	-54.5	57.	-4.	0.	1.63	1.46	0.	-0.00002	2.70	4.20	1.70	4.30	0.70
20.0	0.0	-54.1	54.	-1.	0.	1.50	1.37	0.	0.00000	2.30	4.10	1.20	4.20	0.10
20.0	0.0	-53.8	51.	2.	0.	1.40	1.29	0.	0.00001	1.90	4.10	1.30	4.10	-0.30
20.0	0.0	-53.6	49.	4.	0.	1.31	1.22	0.	0.00002	1.80	4.10	0.70	4.00	-0.30
21.0	0.0	-53.3	46.	6.	0.	1.23	1.15	0.	0.00003	1.60	4.10	0.70	3.80	-0.60
21.0	0.0	-53.1	44.	8.	0.	1.16	1.09	0.	0.00003	1.40	4.10	0.30	3.70	-0.70
21.0	0.0	-52.9	42.	10.	0.	1.10	1.04	0.	0.00004	1.20	4.00	0.60	3.60	-0.80
22.0	0.0	-52.7	40.	11.	0.	1.04	0.99	0.	0.00005	0.90	4.10	0.00	3.50	-1.20
22.0	0.0	-52.6	39.	13.	0.	0.99	0.94	0.	0.00006	0.80	4.10	0.50	3.40	-1.50
22.0	0.0	-52.4	37.	14.	0.	0.95	0.90	0.	0.00006	0.70	4.00	0.60	3.20	-1.40
23.0	0.0	-52.3	36.	15.	0.	0.91	0.87	0.	0.00007	0.50	4.00	0.20	3.00	-1.70
23.0	0.0	-52.1	35.	16.	0.	0.87	0.83	0.	0.00007	0.40	3.90	0.30	3.00	-1.70
23.0	0.0	-52.0	34.	18.	0.	0.83	0.80	0.	0.00008	0.10	3.90	-0.20	2.90	-2.00
0.0	0.0	-97.3	96.	0.	0.	0.03	-0.77	0.	0.00000	-0.10	3.90	-0.40	2.80	-2.20
0.0	0.0	-94.9	83.	11.	0.	-0.56	-1.15	0.	0.00006	-0.20	3.90	-0.20	2.70	-2.30
0.0	0.0	-93.7	76.	17.	0.	-0.95	-1.35	0.	0.00010	-0.40	3.80	-0.70	2.60	-2.40
1.0	0.0	-92.9	72.	21.	0.	-1.22	-1.48	0.	0.00012	-0.60	3.70	-0.30	2.40	-2.50
1.0	0.0	-92.3	68.	24.	0.	-1.40	-1.58	0.	0.00013	-0.70	3.70	-0.50	2.30	-2.70
1.0	0.0	-91.8	65.	27.	0.	-1.53	-1.66	0.	0.00015	-0.80	3.70	-0.60	2.30	-2.70
2.0	0.0	-91.3	62.	29.	0.	-1.63	-1.73	0.	0.00016	-1.00	3.70	-0.70	2.10	-2.90
2.0	0.0	-90.9	60.	31.	0.	-1.71	-1.80	0.	0.00017	-1.10	3.60	-0.90	2.00	-3.00
2.0	0.0	-90.5	58.	33.	0.	-1.79	-1.86	0.	0.00018	-1.30	3.60	-1.00	2.00	-3.20
3.0	0.0	-90.2	56.	34.	0.	-1.85	-1.91	0.	0.00019	-1.40	3.50	-0.90	1.80	-3.30
3.0	0.0	-89.9	54.	36.	0.	-1.90	-1.96	0.	0.00020	-1.50	3.50	-1.10	1.80	-3.30
3.0	0.0	-89.6	53.	37.	0.	-1.96	-2.01	0.	0.00021	-1.60	3.50	-0.90	1.60	-3.40
4.0	0.0	-89.4	51.	38.	0.	-2.00	-2.05	0.	0.00021	-1.70	3.30	-1.20	1.50	-3.70
4.0	0.0	-89.1	50.	40.	0.	-2.05	-2.09	0.	0.00022	-1.90	3.30	-1.40	1.40	-3.80
4.0	0.0	-88.9	48.	41.	0.	-2.08	-2.12	0.	0.00023	-1.90	3.20	-1.60	1.30	-3.80
5.0	0.0	-88.7	47.	42.	0.	-2.12	-2.16	0.	0.00023	-1.90	3.10	-1.70	1.20	-4.00
5.0	0.0	-88.5	46.	43.	0.	-2.15	-2.19	0.	0.00024	-1.90	3.10	-2.10	1.10	-4.00
5.0	0.0	-88.3	45.	43.	0.	-2.19	-2.22	0.	0.00024	-1.80	3.00	-2.20	1.00	-4.10
6.0	0.0	-85.3	30.	55.	0.	-2.05	-1.91	0.	0.00031	-1.80	3.00	-1.60	1.60	-4.00
6.0	0.0	-85.6	32.	54.	0.	-1.96	-1.86	0.	0.00030	-1.90	2.90	-3.30	0.90	-4.20
6.0	0.0	-85.6	32.	53.	0.	-1.90	-1.85	0.	0.00030	-1.80	2.90	-2.70	0.90	-4.30
7.0	0.0	-85.6	32.	53.	0.	-1.88	-1.85	0.	0.00030	-1.80	2.90	-2.60	0.80	-4.50
7.0	0.0	-85.6	32.	53.	0.	-1.87	-1.86	0.	0.00030	-1.90	2.80	-1.80	0.70	-4.40
7.0	61.1	-74.9	26.	49.	0.	-1.79	-1.71	0.	0.00027	-1.80	2.70	-1.90	0.80	-4.20
8.0	126.7	-53.8	14.	40.	0.	-1.59	-1.39	0.	0.00022	-1.60	2.70	-2.10	0.70	-4.00
8.0	193.5	-24.4	0.	25.	0.	-1.24	-0.89	0.	0.00014	-1.20	2.70	-1.60	0.70	-4.10
8.0	258.7	10.5	-17.	6.	0.	-0.75	-0.25	0.	0.00003	-0.70	2.70	-0.90	0.70	-3.60
9.0	321.1	48.9	-33.	-16.	0.	-0.13	0.48	0.	-0.00009	0.00	2.70	-0.30	0.80	-2.50
9.0	378.9	88.2	-49.	-40.	0.	0.57	1.26	0.	-0.00022	0.70	2.60	0.10	0.80	-1.70
9.0	431.5	126.5	-63.	-64.	0.	1.32	2.07	0.	-0.00035	1.40	2.60	0.90	0.90	-1.40
10.0	478.8	162.6	-75.	-88.	0.	2.10	2.87	0.	-0.00048	2.30	2.50	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	-111.	0.	2.86	3.63	0.	-0.00061	3.00	2.50	1.50	1.20	0.60
10.0	553.2	222.0	-91.	-132.	0.	3.59	4.32	0.	-0.00072	3.70	2.50	2.00	1.40	1.60
11.0	580.2	244.0	-94.	-150.	0.	4.26	4.92	0.	-0.00082	4.40	2.50	2.40	1.70	2.60
11.0	599.5	259.6	-95.	-165.	0.	4.84	5.42	0.	-0.00090	5.30	2.70	2.50	2.10	3.30
11.0	611.2	260.5	-92.	-177.	0.	5.32	5.81	0.	-0.00096	5.90	2.70	2.70	2.20	3.10

Model Output 05-02-79 Actuals





05-06 FEBRUARY 1979



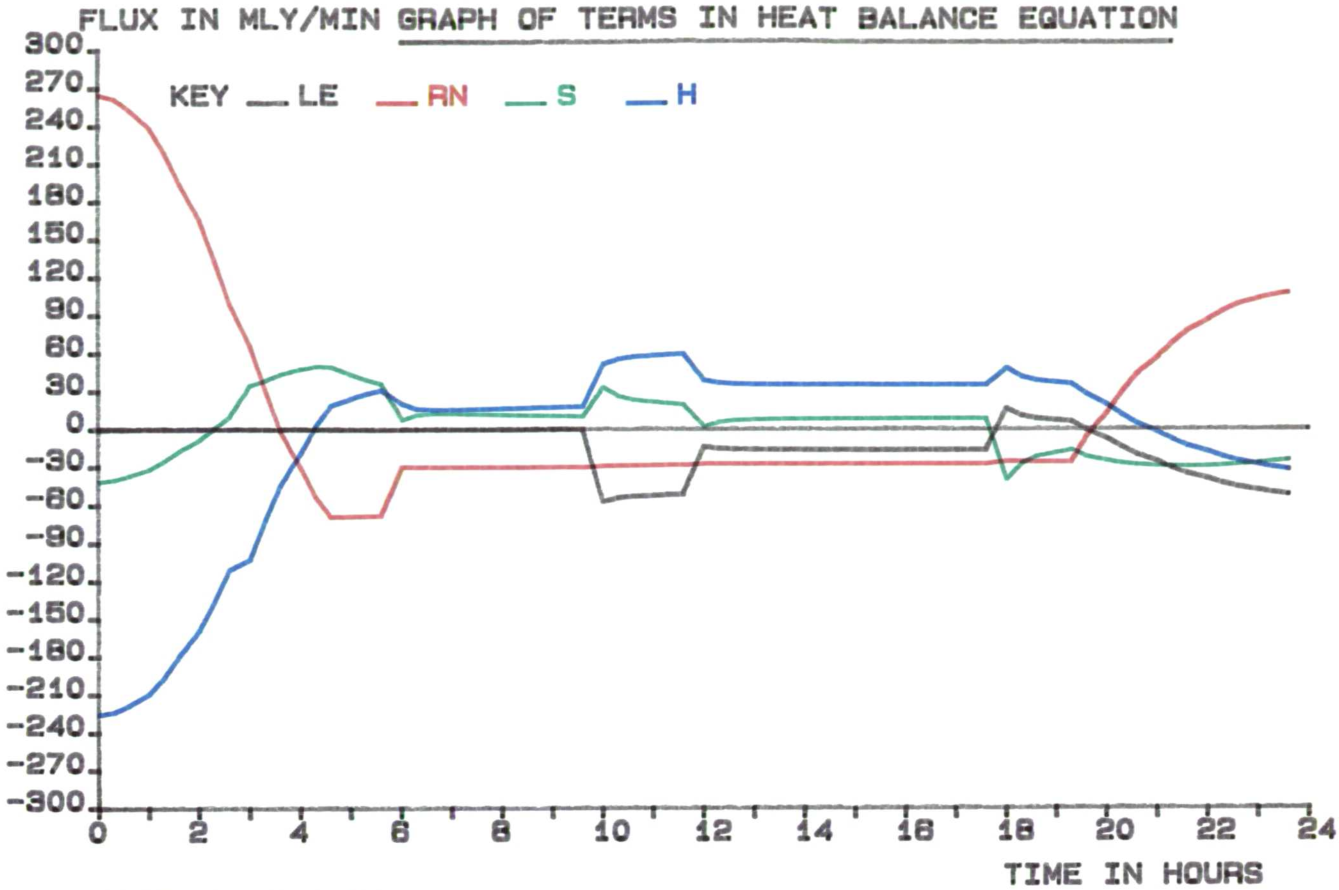
06-02-79

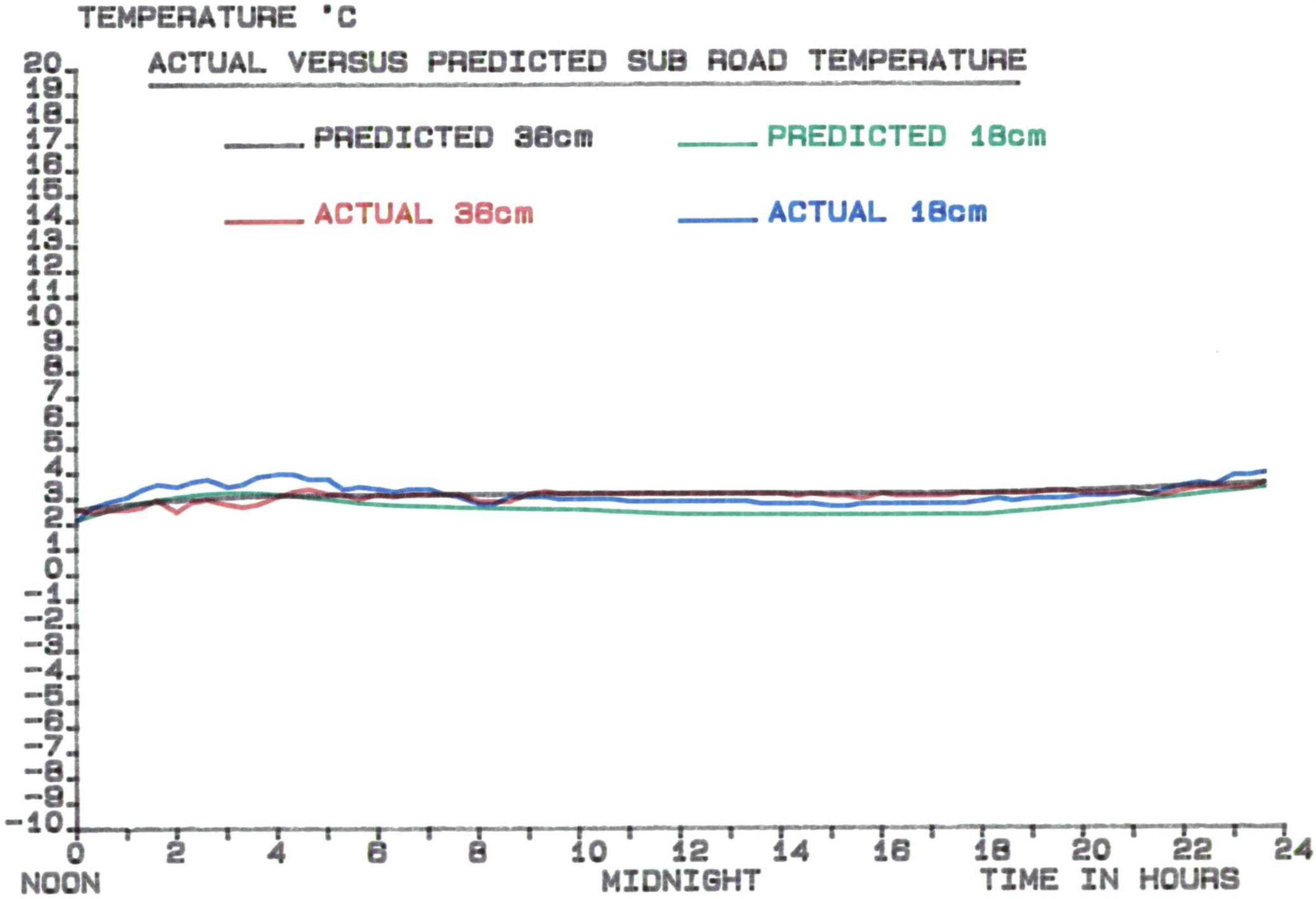
COMPUTED DATA
SAT. VAP. PRESSURE(MB)= 7.05
VAPOUR PRESSURE(MB)= 4.66
REL. HUMIDITY FRACTION = 0.66
APPROX. PRECIP. WATER(MM)= 7.6
ROAD DAMPING DEPTH(CM)= 72.
AIR DAMPING DEPTH(CM)= 3405. 2759.
AIR HEAT TRANSFER COEF.(CGS)= 0.00412 0.00281

DEC	R	T36	T18	TS	UA	D	TIME WET
-15.414	0.986	275.8	275.4	5.9	758. 478.	0.5	22

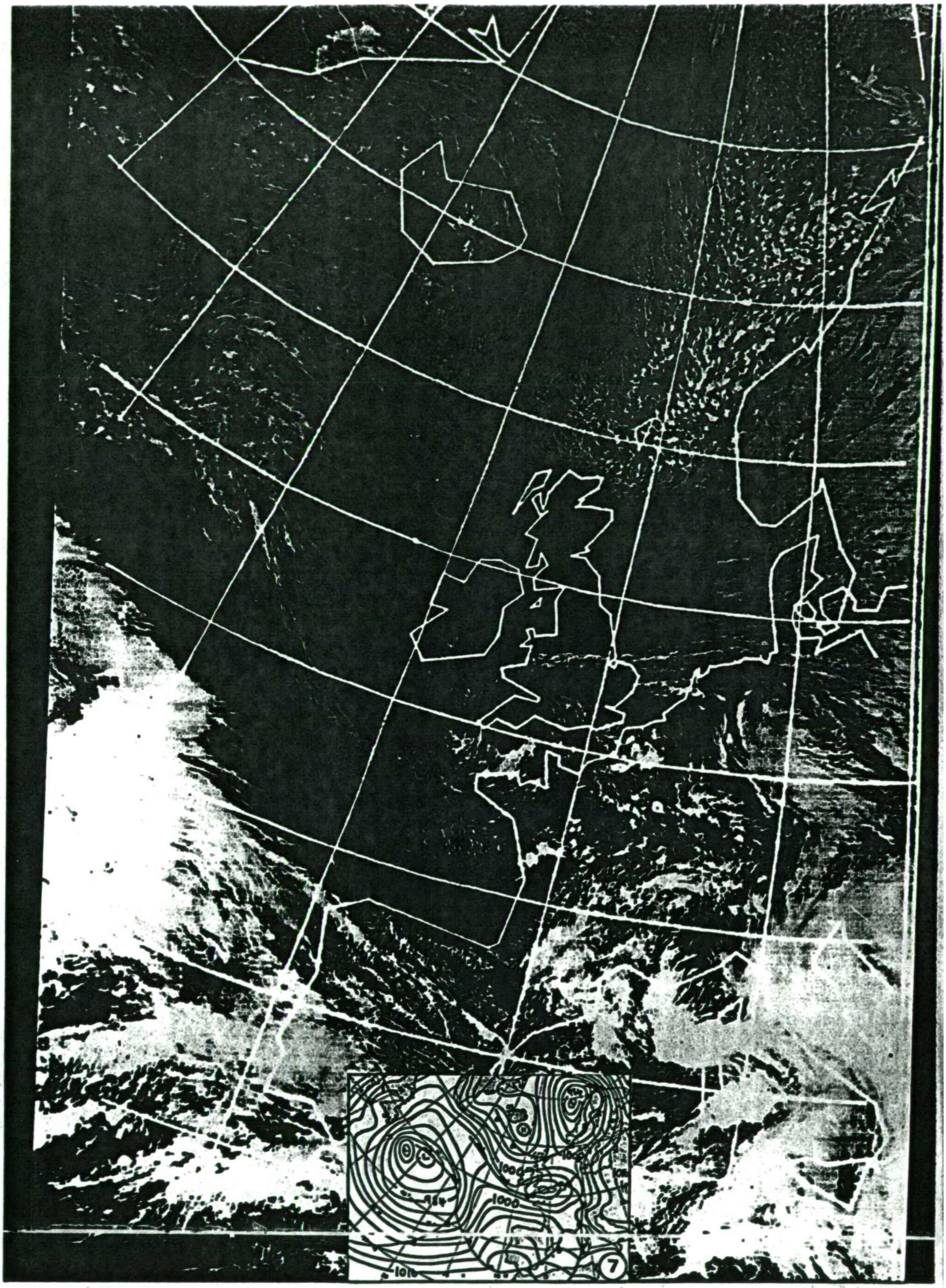
SOLAR TIME	SUN	RN	S	H (ALL MLY./MIN.)	LE	TD	TC (C.)	SUM	RI	TO	T36	Air	T18	Tslab
12.0	543.8	264.6	-41.	-225.	0.	5.90	6.13	1.	-0.00013	5.90	2.60	2.50	2.20	4.20
12.0	540.9	261.7	-39.	-223.	0.	6.00	6.10	0.	-0.00013	5.70	2.50	1.50	2.70	4.00
12.0	531.9	252.9	-36.	-217.	0.	6.00	6.00	0.	-0.00012	6.00	2.60	2.20	2.90	4.30
13.0	517.3	238.7	-31.	-208.	0.	5.92	5.85	0.	-0.00012	6.90	2.60	2.20	3.10	5.90
13.0	496.7	219.0	-24.	-195.	0.	5.78	5.63	0.	-0.00011	5.70	2.70	1.60	3.40	4.30
13.0	470.5	194.5	-17.	-178.	0.	5.56	5.35	0.	-0.00010	6.10	3.00	2.30	3.60	4.90
14.0	439.3	166.0	-8.	-159.	0.	5.29	5.01	0.	-0.00009	5.70	2.50	1.70	3.50	4.60
14.0	402.8	134.0	1.	-136.	0.	4.96	4.62	0.	-0.00008	5.60	2.90	1.90	3.70	4.60
14.0	361.5	99.5	10.	-110.	0.	4.58	4.20	0.	-0.00006	5.60	3.00	2.50	3.80	4.70
15.0	312.4	66.5	35.	-102.	0.	3.97	3.37	0.	-0.00006	5.50	2.80	1.50	3.50	4.10
15.0	263.2	32.0	39.	-72.	0.	3.41	2.85	0.	-0.00004	4.30	2.70	0.90	3.60	2.60
15.0	210.2	-0.7	44.	-44.	0.	2.90	2.38	0.	-0.00003	4.30	2.80	1.60	3.90	2.80
16.0	153.5	-29.6	48.	-19.	0.	2.43	1.95	0.	-0.00001	4.10	3.10	1.40	4.00	2.70
16.0	89.5	-53.0	50.	3.	0.	2.01	1.59	0.	0.00000	4.00	3.30	1.40	4.00	2.40
16.0	0.0	-69.0	50.	19.	0.	1.66	1.32	0.	0.00001	3.90	3.40	1.40	3.30	2.30
17.0	0.0	-68.5	44.	25.	0.	1.44	1.22	0.	0.00001	3.50	3.20	1.20	3.80	1.90
17.0	0.0	-68.2	40.	29.	0.	1.30	1.16	0.	0.00002	3.60	3.20	1.30	3.40	1.90
17.0	0.0	-68.0	36.	32.	0.	1.20	1.11	0.	0.00002	3.00	3.00	1.10	3.50	1.40
18.0	0.0	-29.4	8.	21.	0.	1.45	1.69	0.	0.00001	3.00	3.20	1.20	3.40	1.50
18.0	0.0	-29.6	12.	17.	0.	1.60	1.76	0.	0.00001	2.80	3.10	1.30	3.30	1.40
18.0	0.0	-29.6	13.	16.	0.	1.69	1.77	0.	0.00001	3.10	3.20	1.50	3.40	1.50
19.0	0.0	-29.6	13.	16.	0.	1.73	1.77	0.	0.00001	2.90	3.20	1.60	3.40	1.50
19.0	0.0	-29.6	13.	16.	0.	1.75	1.77	0.	0.00001	3.00	3.20	1.60	3.20	1.50
19.0	0.0	-29.6	12.	17.	0.	1.76	1.76	0.	0.00001	2.70	3.20	1.70	3.10	1.40
20.0	0.0	-29.6	12.	17.	0.	1.76	1.76	0.	0.00001	2.40	2.90	1.40	2.80	1.10
20.0	0.0	-29.6	12.	17.	0.	1.75	1.75	0.	0.00001	2.30	2.90	1.50	2.80	1.00
20.0	0.0	-29.5	11.	18.	0.	1.75	1.74	0.	0.00001	2.30	2.90	1.60	3.10	1.00
21.0	0.0	-29.5	11.	18.	0.	1.74	1.74	0.	0.00001	2.40	3.20	1.90	3.10	1.20
21.0	0.0	-29.5	11.	18.	0.	1.74	1.74	0.	0.00001	2.50	3.30	1.90	3.10	1.20
21.0	0.0	-29.5	10.	18.	0.	1.74	1.73	0.	0.00001	2.30	3.20	1.70	3.00	1.30
22.0	0.0	-28.4	33.	52.	-57.	1.45	1.16	-57.	0.00003	2.30	3.20	1.80	3.00	1.30
22.0	0.0	-28.2	26.	56.	-54.	1.27	1.10	-111.	0.00003	2.30	3.20	1.80	3.00	1.30
22.0	0.0	-28.2	23.	58.	-53.	1.17	1.07	-164.	0.00003	2.30	3.20	1.80	3.00	1.30
23.0	0.0	-28.1	22.	59.	-52.	1.11	1.05	-217.	0.00003	2.30	3.20	1.80	2.90	1.40
23.0	0.0	-28.1	21.	59.	-52.	1.08	1.04	-268.	0.00003	2.30	3.20	1.80	2.90	1.30
23.0	0.0	-28.1	20.	60.	-51.	1.05	1.03	-320.	0.00003	2.30	3.20	1.80	2.90	1.30
0.0	0.0	-27.1	2.	39.	-14.	1.24	1.42	-334.	0.00008	2.30	3.20	1.90	2.90	1.30
0.0	0.0	-27.2	6.	37.	-16.	1.35	1.47	-349.	0.00007	2.20	3.20	1.90	2.90	1.40
0.0	0.0	-27.3	7.	36.	-16.	1.42	1.49	-365.	0.00007	2.30	3.20	1.90	2.90	1.40
1.0	0.0	-27.3	8.	36.	-16.	1.46	1.49	-382.	0.00007	2.30	3.20	1.90	2.90	1.50
1.0	0.0	-27.3	8.	36.	-16.	1.48	1.50	-398.	0.00007	2.30	3.20	2.00	2.90	1.60
1.0	0.0	-27.3	8.	36.	-16.	1.49	1.50	-415.	0.00007	2.30	3.20	1.90	2.80	1.50
2.0	0.0	-27.3	8.	35.	-16.	1.49	1.50	-431.	0.00007	2.20	3.20	1.90	2.80	1.30
2.0	0.0	-27.3	8.	35.	-17.	1.50	1.50	-448.	0.00007	2.20	3.10	2.00	2.80	1.50
2.0	0.0	-27.3	8.	35.	-17.	1.50	1.50	-464.	0.00007	2.30	3.20	2.00	2.80	1.50
3.0	0.0	-27.3	9.	35.	-17.	1.50	1.50	-481.	0.00007	2.20	3.10	1.90	2.70	1.40
3.0	0.0	-27.3	9.	35.	-17.	1.50	1.50	-497.	0.00007	2.20	3.10	2.10	2.70	1.50
3.0	0.0	-27.3	9.	35.	-17.	1.50	1.50	-514.	0.00007	2.20	3.00	2.10	2.80	1.50
4.0	0.0	-27.3	9.	35.	-17.	1.50	1.50	-531.	0.00007	2.50	3.20	2.40	2.60	1.80
4.0	0.0	-27.3	9.	35.	-17.	1.50	1.51	-547.	0.00007	2.50	3.10	2.30	2.80	1.30
4.0	0.0	-27.3	9.	35.	-17.	1.50	1.51	-564.	0.00007	2.60	3.10	2.20	2.60	1.80
5.0	0.0	-27.3	9.	35.	-17.	1.51	1.51	-580.	0.00007	2.60	3.10	2.20	2.80	1.60
5.0	0.0	-27.3	9.	35.	-17.	1.51	1.51	-597.	0.00007	2.60	3.10	2.30	2.80	1.80
5.0	0.0	-27.3	9.	35.	-17.	1.51	1.51	-614.	0.00007	2.70	3.20	2.40	2.80	1.80
6.0	0.0	-25.2	-40.	49.	16.	2.09	2.67	-598.	0.00010	2.80	3.20	2.50	2.90	1.90
6.0	0.0	-25.6	-27.	42.	11.	2.47	2.85	-587.	0.00008	2.90	3.20	2.50	3.00	1.70
6.0	0.0	-25.7	-21.	39.	8.	2.69	2.92	-579.	0.00008	3.00	3.20	2.70	2.90	2.10
7.0	0.0	-25.8	-18.	37.	7.	2.83	2.96	-572.	0.00007	3.10	3.20	2.80	3.00	2.10
7.0	0.6	-25.8	-16.	36.	6.	2.91	2.99	-566.	0.00007	3.30	3.30	2.90	3.00	2.30
7.0	103.7	-5.8	-22.	28.	-1.	3.05	3.19	-566.	0.00006	3.40	3.30	3.10	3.00	2.30
8.0	140.2	12.7	-25.	20.	-7.	3.22	3.39	-574.	0.00004	3.30	3.20	3.10	3.10	2.20
8.0	159.2	29.1	-27.	12.	-14.	3.40	3.59	-588.	0.00002	3.60	3.20	3.20	3.10	2.50
8.0	171.5	43.7	-28.	5.	-20.	3.58	3.76	-608.	0.00001	3.60	3.20	3.20	3.10	2.50
9.0	180.5	56.8	-29.	-2.	-26.	3.76	3.93	-634.	0.00000	3.90	3.20	3.40	3.20	3.00
9.0	187.4	68.2	-29.	-8.	-31.	3.91	4.07	-665.	-0.00002	4.10	3.10	3.60	3.10	3.40
9.0	192.8	78.0	-29.	-13.	-35.	4.06	4.20	-700.	-0.00003	4.20	3.10	3.60	3.30	3.30
10.0	197.2	86.5	-29.	-18.	-40.	4.19	4.32	-740.	[illegible]	[illegible]	3.30	4.00	3.50	3.60
10.0	200.7	93.4	-28.	-22.	-43.	4.30	4.42	-783.	-0.00004	5.00	3.40	4.50	3.60	4.30
10.0	203.4	99.0	-28.	-25.	-46.	4.40	4.50	-829.	-0.00005	5.40	3.40	4.70	3.50	4.80
11.0	205.5	103.3	-27.	-28.	-49.	4.49	4.57	-877.	-0.00006	5.50	3.40	4.70	3.90	5.00
11.0	206.9	106.3	-25.	-30.	-51.	4.55	4.62	-928.	-0.00006	5.50	3.40	4.90	3.90	5.00
11.0	207.8	108.0	-24.	-32.	-52.	4.61	4.67	-980.	-0.00006	6.60	3.60	5.40	4.00	5.60

Model Output 06-02-79 Actuals





06-07 FEBRUARY 1979



07-02-79

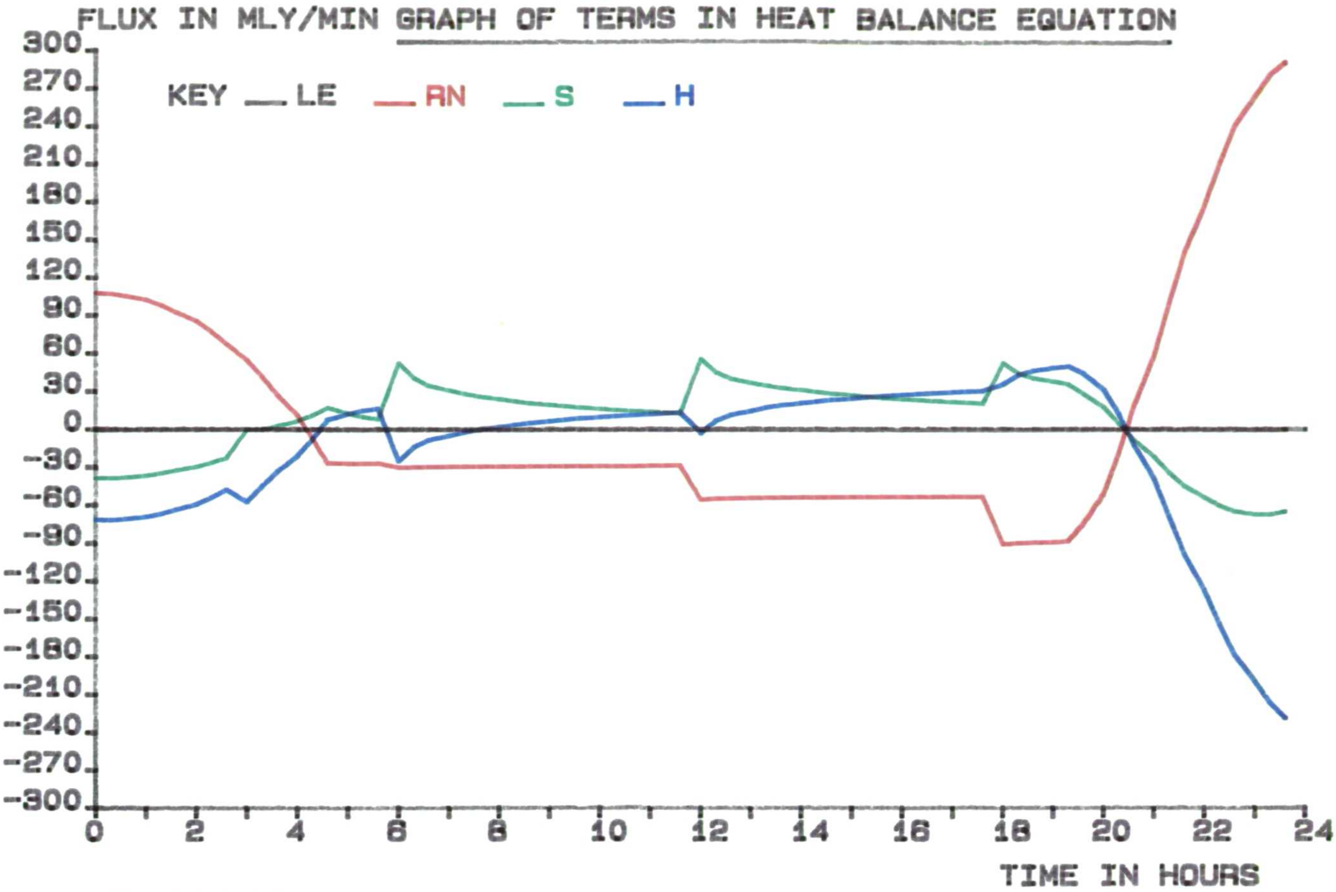
COMPUTED DATA
SAT. VAP. PRESSURE(MB)= 9.28
VAPOUR PRESSURE(MB)= 9.00
REL. HUMIDITY FRACTION = 0.97
APPROX. PRECIP. WATER(MM)= 14.1
ROAD DAMPING DEPTH(CM)= 72.
AIR DAMPING DEPTH(CM)= 3058. 3076.
AIR HEAT TRANSFER COEF.(CGS)= 0.00339 0.00343

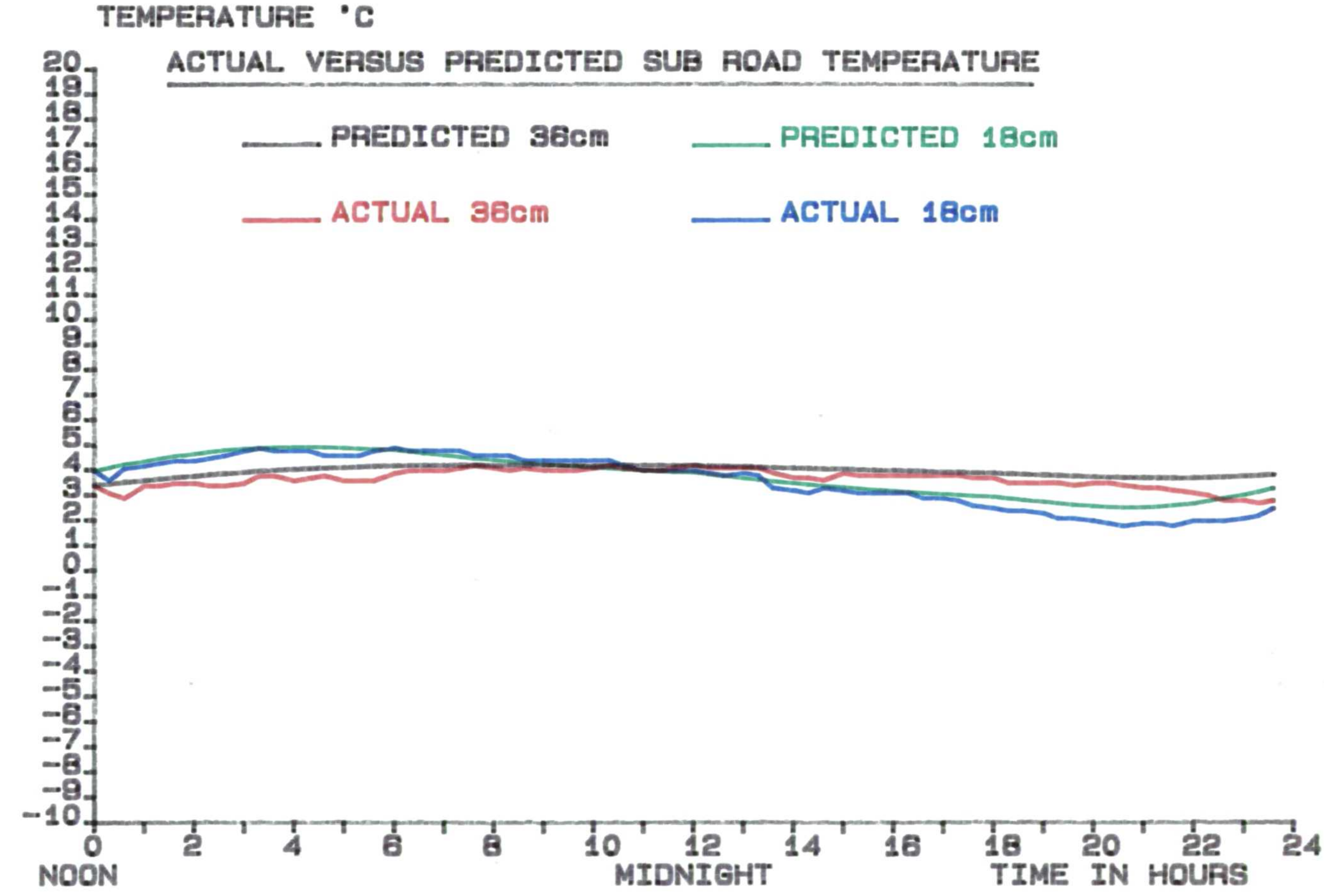
DEC	R	T36	T18	TS	UA	D	TIME WET
-15.100	0.986276	6277.2	6.1	599.	607.	0.5	0

SOLAR TIME	SUN	RN	S	H	LE	TD	TC	SUM	RI
			(ALL MLY./MIN.)				(C.)		
12.0	208.1	108.1	-38.	-70.	0.	6.10	7.65	1.	-0.00007
12.0	207.8	107.5	-38.	-71.	0.	6.88	7.65	0.	-0.00008
12.0	206.9	105.7	-37.	-70.	0.	7.25	7.63	0.	-0.00007
13.0	205.5	102.7	-36.	-68.	0.	7.43	7.60	0.	-0.00007
13.0	203.5	98.4	-34.	-66.	0.	7.49	7.55	0.	-0.00007
13.0	200.8	92.8	-31.	-62.	0.	7.48	7.48	0.	-0.00007
14.0	197.3	85.9	-29.	-58.	0.	7.44	7.40	0.	-0.00006
14.0	193.0	77.6	-26.	-53.	0.	7.37	7.29	0.	-0.00006
14.0	187.5	67.7	-22.	-47.	0.	7.27	7.16	0.	-0.00005
15.0	180.7	55.1	1.	-57.	0.	6.92	6.57	0.	-0.00006
15.0	171.8	42.4	1.	-44.	0.	6.61	6.31	0.	-0.00005
15.0	159.6	27.9	4.	-32.	0.	6.34	6.07	0.	-0.00003
16.0	141.0	11.7	7.	-20.	0.	6.08	5.82	0.	-0.00002
16.0	105.6	-6.5	12.	-7.	0.	5.81	5.54	0.	-0.00001
16.0	5.5	-26.4	18.	9.	0.	5.52	5.23	0.	0.00001
17.0	0.0	-26.8	14.	13.	0.	5.33	5.13	0.	0.00001
17.0	0.0	-26.7	11.	16.	0.	5.20	5.08	0.	0.00002
17.0	0.0	-26.6	9.	18.	0.	5.12	5.04	0.	0.00002
18.0	0.0	-29.8	53.	-24.	0.	4.51	3.90	0.	-0.00003
18.0	0.0	-29.4	42.	-13.	0.	4.09	3.67	0.	-0.00001
18.0	0.0	-29.1	36.	-7.	0.	3.83	3.56	0.	-0.00001
19.0	0.0	-29.0	32.	-4.	0.	3.66	3.49	0.	0.00000
19.0	0.0	-28.9	29.	-1.	0.	3.54	3.43	0.	0.00000
19.0	0.0	-28.8	27.	1.	0.	3.46	3.38	0.	0.00000
20.0	0.0	-28.7	25.	3.	0.	3.40	3.34	0.	0.00000
20.0	0.0	-28.6	23.	5.	0.	3.36	3.31	0.	0.00001
20.0	0.0	-28.5	22.	6.	0.	3.32	3.28	0.	0.00001
21.0	0.0	-28.5	20.	7.	0.	3.29	3.25	0.	0.00001
21.0	0.0	-28.4	19.	9.	0.	3.26	3.23	0.	0.00001
21.0	0.0	-28.4	18.	10.	0.	3.23	3.21	0.	0.00001
22.0	0.0	-28.3	17.	11.	0.	3.21	3.19	0.	0.00001
22.0	0.0	-28.3	16.	12.	0.	3.19	3.17	0.	0.00001
22.0	0.0	-28.3	15.	12.	0.	3.17	3.15	0.	0.00001
23.0	0.0	-28.2	14.	13.	0.	3.16	3.14	0.	0.00001
23.0	0.0	-28.2	14.	14.	0.	3.14	3.13	0.	0.00001
23.0	0.0	-28.2	13.	14.	0.	3.13	3.11	0.	0.00002
0.0	0.0	-55.2	56.	-2.	0.	2.59	2.05	0.	0.00000
0.0	0.0	-54.5	46.	8.	0.	2.22	1.85	0.	0.00001
0.0	0.0	-54.1	40.	13.	0.	1.98	1.75	0.	0.00001
1.0	0.0	-53.9	37.	16.	0.	1.84	1.69	0.	0.00002
1.0	0.0	-53.7	35.	18.	0.	1.74	1.64	0.	0.00002
1.0	0.0	-53.6	33.	20.	0.	1.67	1.60	0.	0.00002
2.0	0.0	-53.4	32.	22.	0.	1.62	1.57	0.	0.00002
2.0	0.0	-53.3	30.	23.	0.	1.58	1.54	0.	0.00002
2.0	0.0	-53.2	29.	24.	0.	1.55	1.51	0.	0.00003
3.0	0.0	-53.2	28.	26.	0.	1.52	1.49	0.	0.00003
3.0	0.0	-53.1	27.	27.	0.	1.49	1.47	0.	0.00003
3.0	0.0	-53.0	26.	27.	0.	1.47	1.45	0.	0.00003
4.0	0.0	-53.0	25.	28.	0.	1.45	1.43	0.	0.00003
4.0	0.0	-52.9	24.	29.	0.	1.44	1.42	0.	0.00003
4.0	0.0	-52.8	23.	30.	0.	1.42	1.40	0.	0.00003
5.0	0.0	-52.8	22.	30.	0.	1.41	1.39	0.	0.00003
5.0	0.0	-52.8	22.	31.	0.	1.39	1.38	0.	0.00003
5.0	0.0	-52.7	21.	32.	0.	1.36	1.37	0.	0.00003
6.0	0.0	-90.1	53.	37.	0.	0.97	0.56	0.	0.00004
6.0	0.0	-89.2	45.	44.	0.	0.69	0.42	0.	0.00005
6.0	0.0	-88.8	41.	48.	0.	0.52	0.34	0.	0.00005
7.0	0.0	-88.5	39.	50.	0.	0.41	0.30	0.	0.00005
7.0	6.9	-87.6	37.	51.	0.	0.34	0.27	0.	0.00005
7.0	72.3	-74.2	29.	45.	0.	0.37	0.39	0.	0.00005
8.0	138.4	-50.7	18.	32.	0.	0.51	0.65	0.	0.00003
8.0	205.3	-19.1	6.	13.	0.	0.77	1.04	0.	0.00001
8.0	270.5	18.1	-7.	-11.	0.	1.15	1.52	0.	-0.00001
9.0	332.8	58.7	-21.	-38.	0.	1.61	2.08	0.	-0.00004
9.0	390.5	99.9	-33.	-68.	0.	2.15	2.68	0.	-0.00007
9.0	443.1	140.2	-44.	-97.	0.	2.71	3.28	0.	-0.00010
10.0	490.3	178.2	-53.	-126.	0.	[illegible]	[illegible]	[illegible]	[illegible]
10.0	530.9	212.0	-60.	-153.	0.	3.85	4.41	0.	-0.00016
10.0	564.7	240.9	-64.	-177.	0.	4.37	4.90	0.	-0.00018
11.0	591.7	264.3	-67.	-198.	0.	4.85	5.32	0.	-0.00021
11.0	611.0	281.0	-66.	-215.	0.	5.26	5.66	0.	-0.00022
11.0	622.7	290.9	-64.	-228.	0.	5.58	5.91	0.	-0.00024

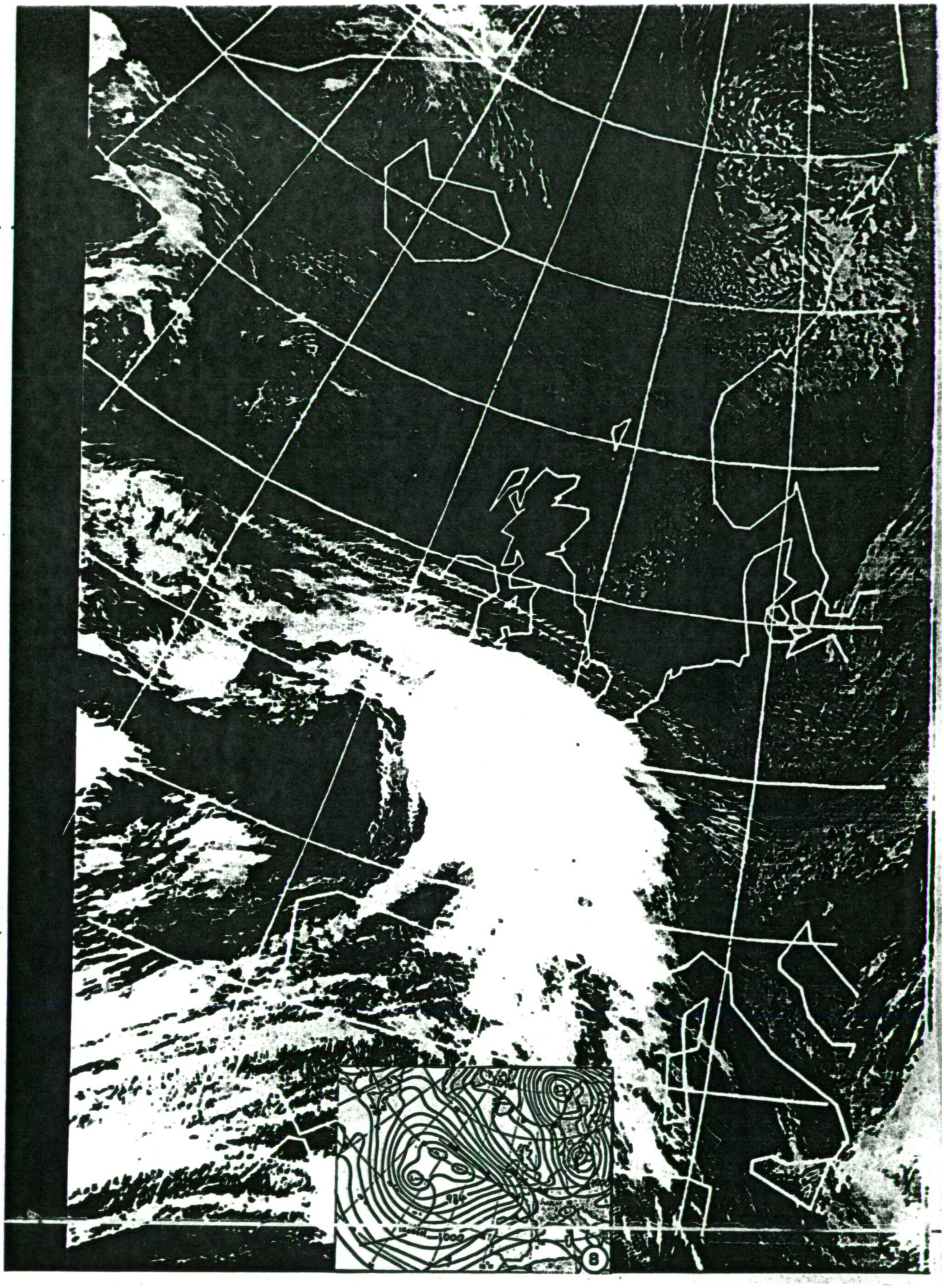
~~TO~~	~~T36~~	~~Air~~	~~T18~~	~~Tslab~~
6.10	3.40	5.40	4.00	5.80
6.00	3.10	5.30	3.60	5.90
6.00	2.90	5.30	4.10	5.70
6.30	3.40	5.80	4.20	5.90
6.50	3.40	6.10	4.30	6.30
6.70	3.50	6.20	4.40	6.30
6.60	3.50	6.30	4.40	6.10
6.70	3.40	6.30	4.50	6.10
6.60	3.40	6.30	4.60	6.00
6.80	3.50	6.20	4.80	6.00
6.50	3.80	5.90	4.90	5.80
6.30	3.80	5.70	4.80	5.60
6.50	3.60	5.10	4.80	5.20
6.00	3.70	5.00	4.80	4.90
5.70	3.80	4.90	4.60	4.90
5.30	3.60	4.50	4.60	4.40
5.20	3.60	4.40	4.60	4.30
5.00	3.60	4.10	4.60	4.20
5.10	3.90	3.80	4.90	4.30
5.00	4.00	3.80	4.80	4.00
4.80	4.00	3.60	4.80	4.00
4.60	4.00	3.40	4.80	3.70
4.50	4.10	3.40	4.80	3.70
4.50	4.20	3.40	4.60	3.60
4.20	4.10	3.10	4.60	3.30
4.00	4.00	3.00	4.60	3.20
4.10	4.10	3.20	4.40	3.30
4.10	4.00	3.10	4.40	3.10
3.80	4.00	3.10	4.40	3.10
3.60	4.00	3.00	4.40	2.90
3.70	4.10	3.10	4.40	3.00
3.60	4.20	3.00	4.40	2.90
3.60	4.10	2.80	4.20	2.70
3.10	4.00	2.60	4.00	2.50
2.90	4.00	2.40	4.00	2.30
3.00	4.10	2.60	4.00	2.40
3.20	4.20	2.60	4.00	2.40
2.80	4.10	2.50	3.90	2.40
2.60	4.10	2.20	3.80	1.80
2.10	4.10	2.00	3.90	1.20
2.10	4.10	2.00	3.80	1.20
1.80	3.90	1.70	3.30	1.00
1.60	3.70	1.50	3.20	0.70
1.70	3.70	1.70	3.10	0.70
1.40	3.60	1.40	3.30	0.50
2.00	3.90	1.60	3.20	1.10
2.00	3.80	1.90	3.10	1.10
1.50	3.80	1.60	3.10	0.50
1.10	3.80	1.60	3.10	0.10
0.90	3.80	1.60	3.10	-0.20
0.70	3.80	1.70	2.90	-0.30
0.40	3.80	1.50	2.90	-0.60
0.30	3.80	1.30	2.80	-0.70
0.00	3.70	0.80	2.60	-1.10
-0.10	3.70	0.70	2.50	-1.30
-0.40	3.50	0.50	2.40	-1.70
-0.50	3.50	0.50	2.40	-1.80
-0.50	3.50	0.40	2.30	-2.00
-0.50	3.50	0.40	2.10	-2.20
-0.60	3.40	0.00	2.10	-2.50
-0.30	3.50	-0.10	2.00	-2.10
0.00	3.50	0.50	1.90	-1.70
0.50	3.40	0.60	1.80	-1.40
1.10	3.30	1.10	1.90	-0.70
2.00	3.30	1.40	1.90	0.70
2.40	[illegible]	[illegible]	[illegible]	[illegible]
2.40	3.10	1.20	2.00	1.00
2.70	3.00	1.40	2.00	1.60
3.20	2.80	1.40	2.00	1.80
3.20	2.80	1.70	2.10	2.30
3.50	2.70	2.00	2.20	2.70
3.90	2.80	2.30	2.50	[illegible]

Model Output 07-02-79 Actuals





07-08 FEBRUARY 1979



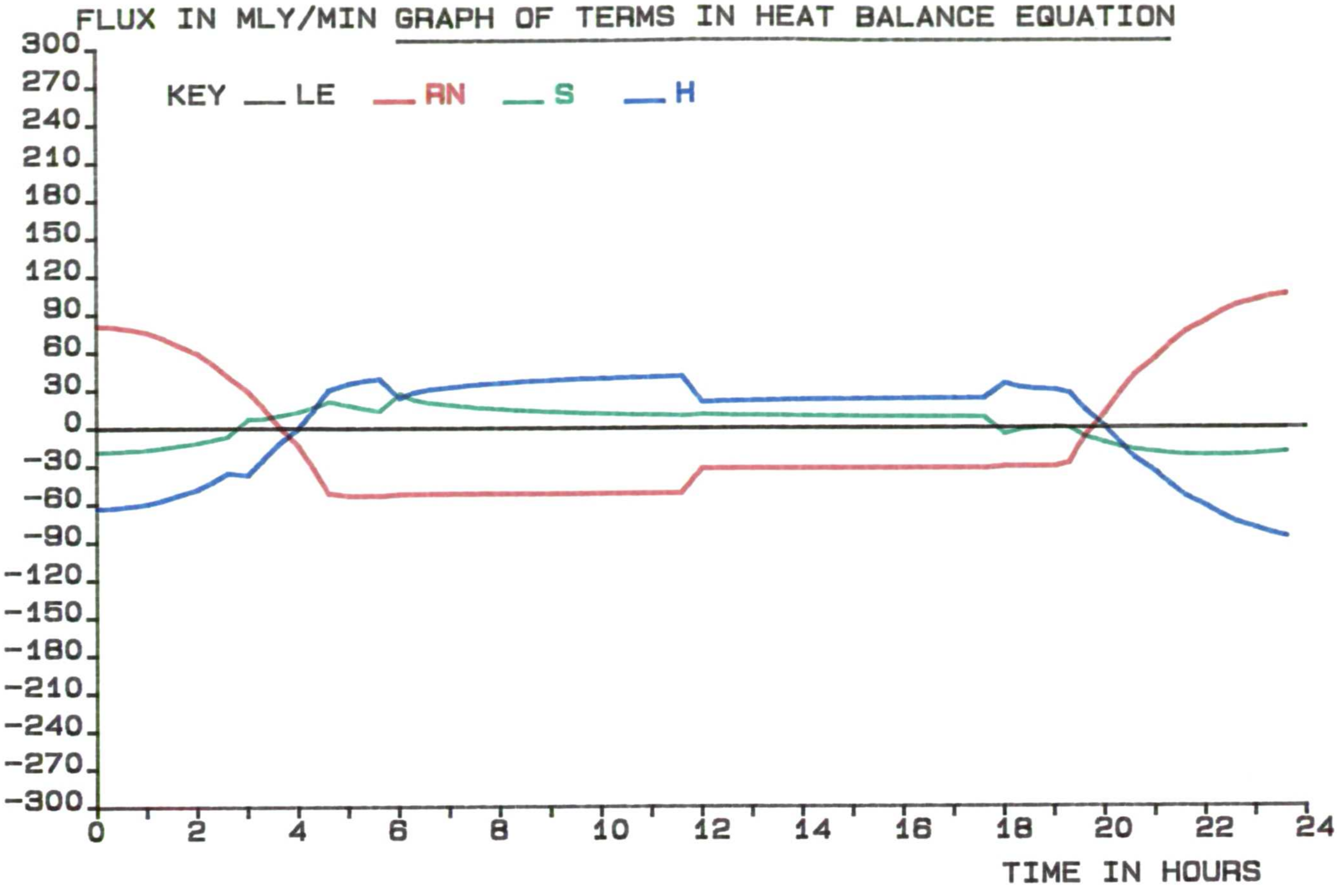
08-02-79

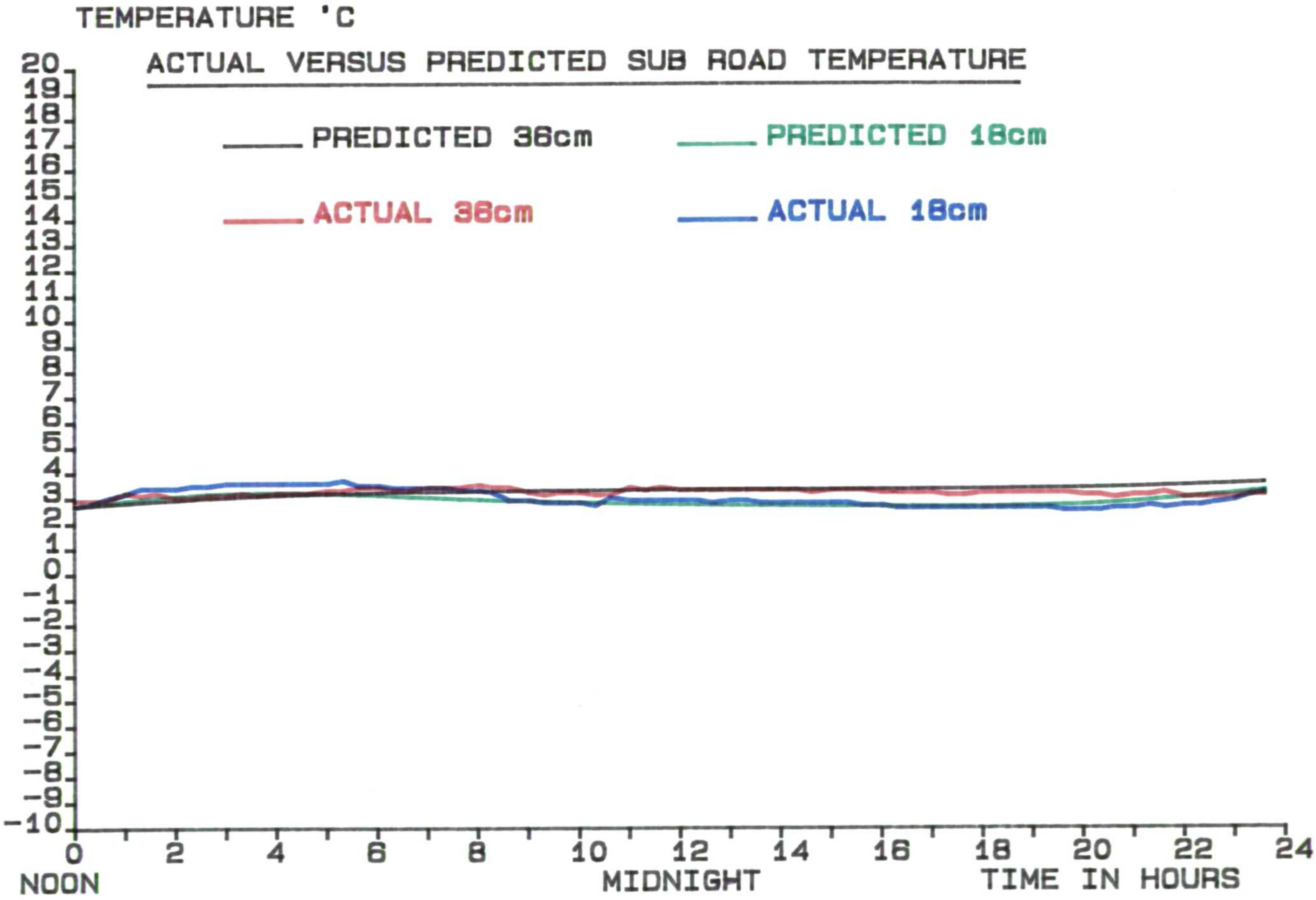
[illegible]
SAT. VAP. PRESSURE(MB)= 7.68
VAPOUR PRESSURE(MB)= 5.22
REL. HUMIDITY FRACTION = 0.68
APPROX. PRECIP. WATER(MM)= 8.4
ROAD DAMPING DEPTH(CM)= 72.
AIR DAMPING DEPTH(CM)= 3680. 3542.
AIR HEAT TRANSFER COEF.(CGS)= 0.00475 0.00443

DEC	R	T36	T18	TS	UA	D	TIME WET
-14.783	0.9872	75.9	275.9	4.6	898.	820. 0.5	0

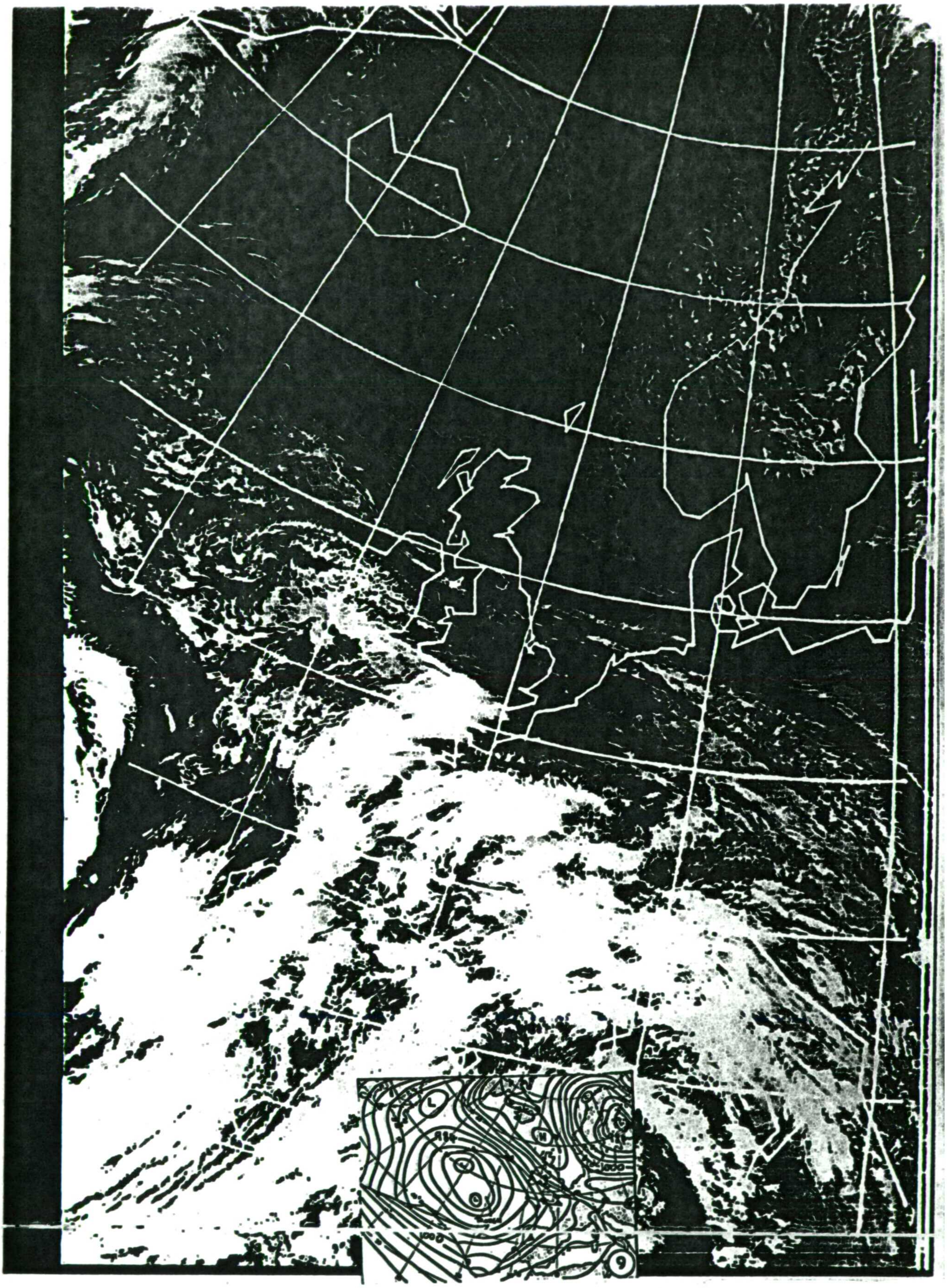
SOLAR TIME	SUN	RN	S	H	LE	TD	TC	SUM	RI	TO	T36	Air	T18	Tslab
		(ALL	MLY./MIN.)				(C.)							
12.0	208.6	80.8	-19.	-63.	0.	4.60	4.49	1.	-0.00002					
12.0	208.3	80.2	-18.	-63.	0.	4.54	4.49	0.	-0.00002	4.60	2.9	2.80	2.70	3.80
12.0	207.5	78.4	-18.	-61.	0.	4.51	4.47	0.	-0.00002	4.70	2.9	2.80	2.80	3.70
13.0	206.1	75.5	-17.	-60.	0.	4.47	4.44	0.	-0.00002	4.70	2.9	2.90	3.00	3.70
13.0	204.1	71.2	-15.	-57.	0.	4.44	4.40	0.	-0.00002	5.20	3.2	3.50	3.20	4.30
13.0	201.4	65.7	-14.	-53.	0.	4.39	4.34	0.	-0.00002	5.50	3.1	3.40	3.40	4.10
14.0	198.0	58.9	-11.	-48.	0.	4.33	4.27	0.	-0.00002	5.20	3.2	3.50	3.40	4.10
14.0	193.7	50.7	-9.	-42.	0.	4.26	4.19	0.	-0.00001	5.10	3.0	3.30	3.40	3.70
14.0	188.3	41.0	-6.	-35.	0.	4.17	4.09	0.	-0.00001	4.90	3.0	3.30	3.50	3.70
15.0	181.6	29.0	7.	-37.	0.	3.94	3.71	0.	-0.00001	5.00	3.1	3.20	3.50	3.50
15.0	172.9	16.3	8.	-25.	0.	3.74	3.53	0.	-0.00001	4.60	3.1	3.20	3.60	3.30
15.0	161.1	2.0	10.	-13.	0.	3.55	3.36	0.	0.00000	4.30	3.2	3.10	3.60	2.90
16.0	143.3	-13.9	13.	0.	0.	3.36	3.17	0.	0.00000	4.20	3.1	3.00	3.60	2.70
16.0	110.3	-31.9	17.	14.	0.	3.16	2.96	0.	0.00001	4.00	3.2	2.90	3.60	2.20
16.0	18.6	-52.0	21.	30.	0.	2.94	2.73	0.	0.00001	3.60	3.2	2.70	3.60	2.00
17.0	0.0	-53.9	18.	35.	0.	2.80	2.65	0.	0.00001	3.70	3.2	2.80	3.60	1.80
17.0	0.0	-53.7	15.	38.	0.	2.71	2.62	0.	0.00001	3.60	3.3	2.60	3.60	1.60
17.0	0.0	-53.7	14.	39.	0.	2.65	2.60	0.	0.00001	3.10	3.3	2.50	3.70	1.40
18.0	0.0	-52.4	28.	24.	0.	2.43	2.22	0.	0.00001	3.10	3.4	2.40	3.50	1.30
18.0	0.0	-52.1	23.	29.	0.	2.29	2.15	0.	0.00001	2.90	3.4	2.40	3.50	1.00
18.0	0.0	-52.0	20.	31.	0.	2.20	2.11	0.	0.00001	2.80	3.3	2.30	3.40	1.10
19.0	0.0	-51.9	18.	33.	0.	2.15	2.09	0.	0.00001	2.70	3.3	2.40	3.40	1.10
19.0	0.0	-51.9	17.	34.	0.	2.11	2.07	0.	0.00001	2.70	3.4	2.50	3.40	1.00
19.0	0.0	-51.8	16.	35.	0.	2.08	2.06	0.	0.00001	2.60	3.4	2.40	3.40	1.10
20.0	0.0	-51.8	15.	36.	0.	2.06	2.04	0.	0.00001	2.50	3.4	2.40	3.30	0.90
20.0	0.0	-51.7	14.	37.	0.	2.05	2.03	0.	0.00001	2.50	3.5	2.40	3.30	0.80
20.0	0.0	-51.7	13.	37.	0.	2.03	2.02	0.	0.00001	2.40	3.4	2.40	3.20	0.90
21.0	0.0	-51.7	13.	38.	0.	2.02	2.01	0.	0.00001	2.40	3.4	2.40	2.90	1.10
										2.10	3.2	2.10	2.90	0.70
21.0	0.0	-51.6	12.	38.	0.	2.01	2.00	0.	0.00001	2.00	3.1	2.10	2.80	0.60
21.0	0.0	-51.6	12.	39.	0.	2.01	2.00	0.	0.00001	1.90	3.2	2.00	2.80	0.60
22.0	0.0	-51.6	11.	39.	0.	2.00	1.99	0.	0.00001	2.00	3.2	2.00	2.80	0.70
22.0	0.0	-51.6	11.	40.	0.	1.99	1.99	0.	0.00001	2.00	3.1	2.10	2.70	0.70
22.0	0.0	-51.6	11.	40.	0.	1.99	1.98	0.	0.00001	1.90	3.1	2.00	3.00	0.70
23.0	0.0	-51.5	10.	40.	0.	1.98	1.98	0.	0.00001	2.20	3.4	2.20	2.90	0.90
23.0	0.0	-51.5	10.	41.	0.	1.98	1.97	0.	0.00001	2.10	3.3	2.20	2.90	1.00
23.0	0.0	-51.5	10.	41.	0.	1.97	1.97	0.	0.00001	2.20	3.4	2.10	2.90	1.10
0.0	0.0	-32.2	11.	21.	0.	1.95	1.93	0.	0.00001	2.20	3.3	2.30	2.90	1.20
0.0	0.0	-32.1	10.	21.	0.	1.94	1.92	0.	0.00001	2.10	3.3	2.30	2.90	1.10
0.0	0.0	-32.1	10.	21.	0.	1.93	1.92	0.	0.00001	2.20	3.3	2.30	2.80	1.30
1.0	0.0	-32.1	10.	22.	0.	1.92	1.91	0.	0.00001	2.30	3.3	2.30	2.90	1.40
1.0	0.0	-32.1	10.	22.	0.	1.92	1.91	0.	0.00001	2.30	3.3	2.40	2.90	1.40
1.0	0.0	-32.1	9.	22.	0.	1.91	1.91	0.	0.00001	2.30	3.3	2.40	2.80	1.40
2.0	0.0	-32.1	9.	22.	0.	1.91	1.90	0.	0.00001	2.20	3.3	2.30	2.80	1.40
2.0	0.0	-32.1	9.	22.	0.	1.91	1.90	0.	0.00001	2.10	3.3	2.00	2.80	1.30
2.0	0.0	-32.1	9.	23.	0.	1.90	1.90	0.	0.00001	2.00	3.2	2.00	2.80	1.20
3.0	0.0	-32.1	9.	23.	0.	1.90	1.90	0.	0.00001	1.90	3.3	1.90	2.60	1.10
3.0	0.0	-32.1	9.	23.	0.	1.90	1.90	0.	0.00001	1.90	3.3	1.90	2.80	1.20
3.0	0.0	-32.1	9.	23.	0.	1.90	1.90	0.	0.00001	1.90	3.3	1.90	2.70	1.10
4.0	0.0	-32.1	9.	23.	0.	1.90	1.89	0.	0.00001	1.80	3.2	1.50	2.70	1.00
4.0	0.0	-32.1	8.	23.	0.	1.89	1.89	0.	0.00001	1.70	3.2	1.40	2.60	0.90
4.0	0.0	-32.1	8.	23.	0.	1.89	1.89	0.	0.00001	1.60	3.2	1.30	2.60	0.80
5.0	0.0	-32.1	8.	23.	0.	1.89	1.89	0.	0.00001	1.60	3.2	1.10	2.60	0.70
5.0	0.0	-32.1	8.	23.	0.	1.89	1.89	0.	0.00001	1.50	3.1	1.20	2.60	0.50
5.0	0.0	-32.1	8.	23.	0.	1.89	1.89	0.	0.00001	1.50	3.1	1.30	2.60	0.60
6.0	0.0	-30.7	-5.	35.	0.	2.05	2.21	0.	0.00002	1.80	3.2	1.50	2.60	0.90
6.0	0.0	-30.8	-2.	32.	0.	2.15	2.26	0.	0.00001	1.90	3.2	1.60	2.60	0.70
6.0	0.0	-30.8	0.	30.	0.	2.21	2.28	0.	0.00001	1.80	3.2	1.90	2.60	1.10
7.0	0.0	-30.9	1.	30.	0.	2.25	2.29	0.	0.00001	1.80	3.2	1.80	2.60	0.80
7.0	26.7	-27.7	0.	27.	0.	2.29	2.33	0.	0.00001	2.00	3.2	1.80	2.60	0.50
7.0	113.1	-7.1	-7.	14.	0.	2.41	2.53	0.	0.00001	1.90	3.2	1.90	2.50	0.90
8.0	144.8	11.1	-12.	0.	0.	2.58	2.75	0.	0.00000	2.10	3.1	2.00	2.50	0.90
8.0	162.1	27.3	-15.	-12.	0.	2.77	2.95	0.	-0.00001	2.20	3.1	2.00	2.50	0.90
8.0	173.7	41.8	-18.	-25.	0.	2.95	3.14	0.	-0.00001	2.70	3.0	2.10	2.60	1.00
9.0	182.3	54.7	-20.	-36.	0.	3.13	3.31	0.	-0.00002	3.00	3.1	2.30	2.60	1.30
9.0	188.9	66.0	-21.	-46.	0.	3.30	3.47	0.	-0.00002	3.30	3.1	2.50	2.70	1.90
9.0	194.2	75.8	-22.	-55.	0.	3.46	3.61	0.	-0.00002	3.40	3.2	2.50	2.60	1.70
10.0	198.5	84.1	-22.	-63.	0.	3.60	3.74	0.	-0.00003	[illegible]	[illegible]	2.40	[illegible]	[illegible]
10.0	[illegible]	[illegible]	[illegible]	[illegible]	0.	3.72	3.84	0.	-0.00003	4.20	3.0	2.90	2.70	2.80
10.0	204.6	96.4	-22.	-75.	0.	3.83	3.93	0.	-0.00003	4.20	3.0	3.00	2.80	3.10
11.0	206.6	100.6	-21.	-80.	0.	3.92	4.01	0.	-0.00004	4.90	3.0	3.30	2.90	3.60
11.0	208.0	103.6	-20.	-84.	0.	4.00	4.07	0.	-0.00004	5.30	3.1	3.50	3.10	4.00
11.0	208.8	105.3	-19.	-87.	0.	4.06	4.12	0.	-0.00004	5.70	3.1	3.60	3.20	4.50

Model Output 08-02-79 Actuals





08-09 FEBRUARY 1979



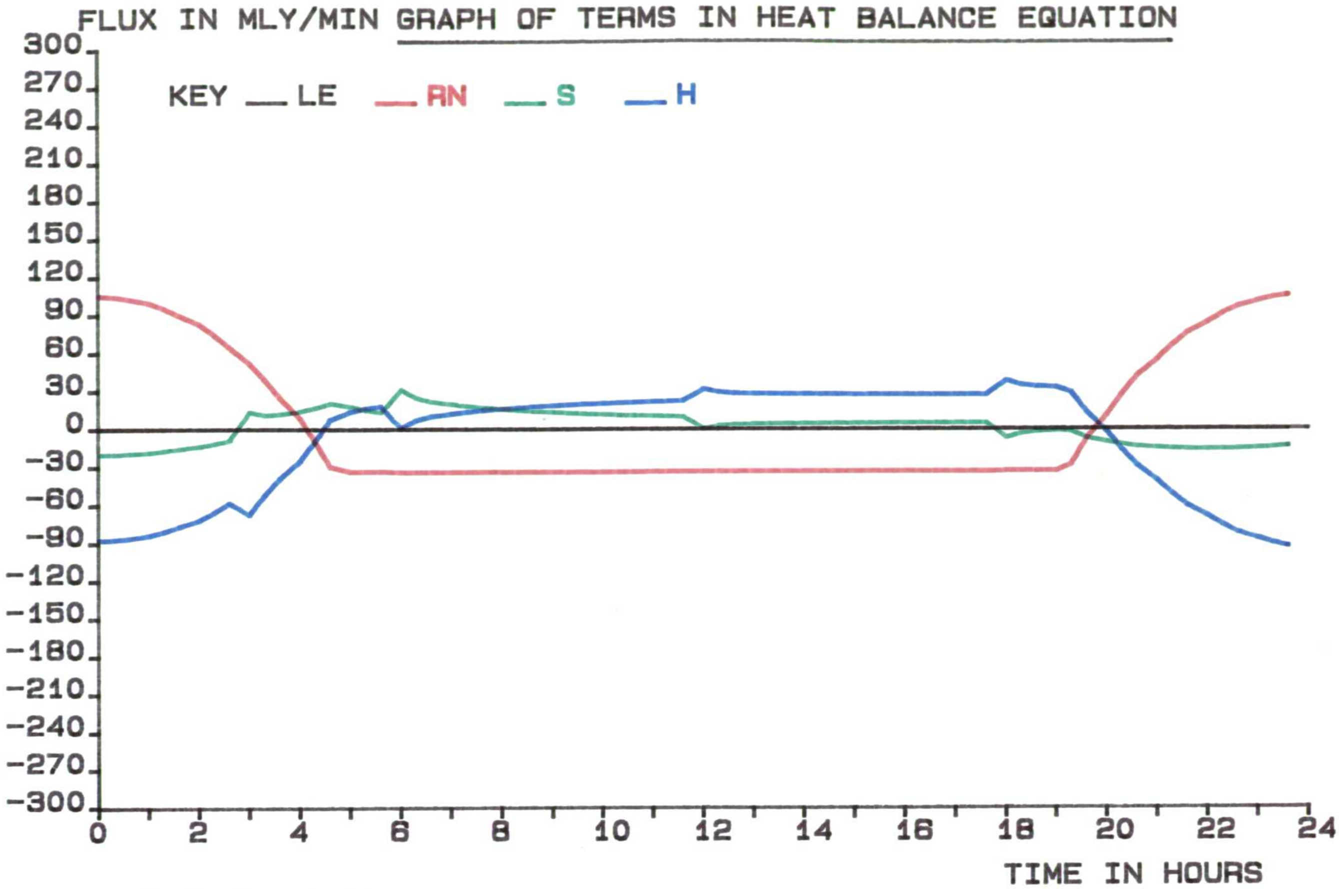
09-02-79

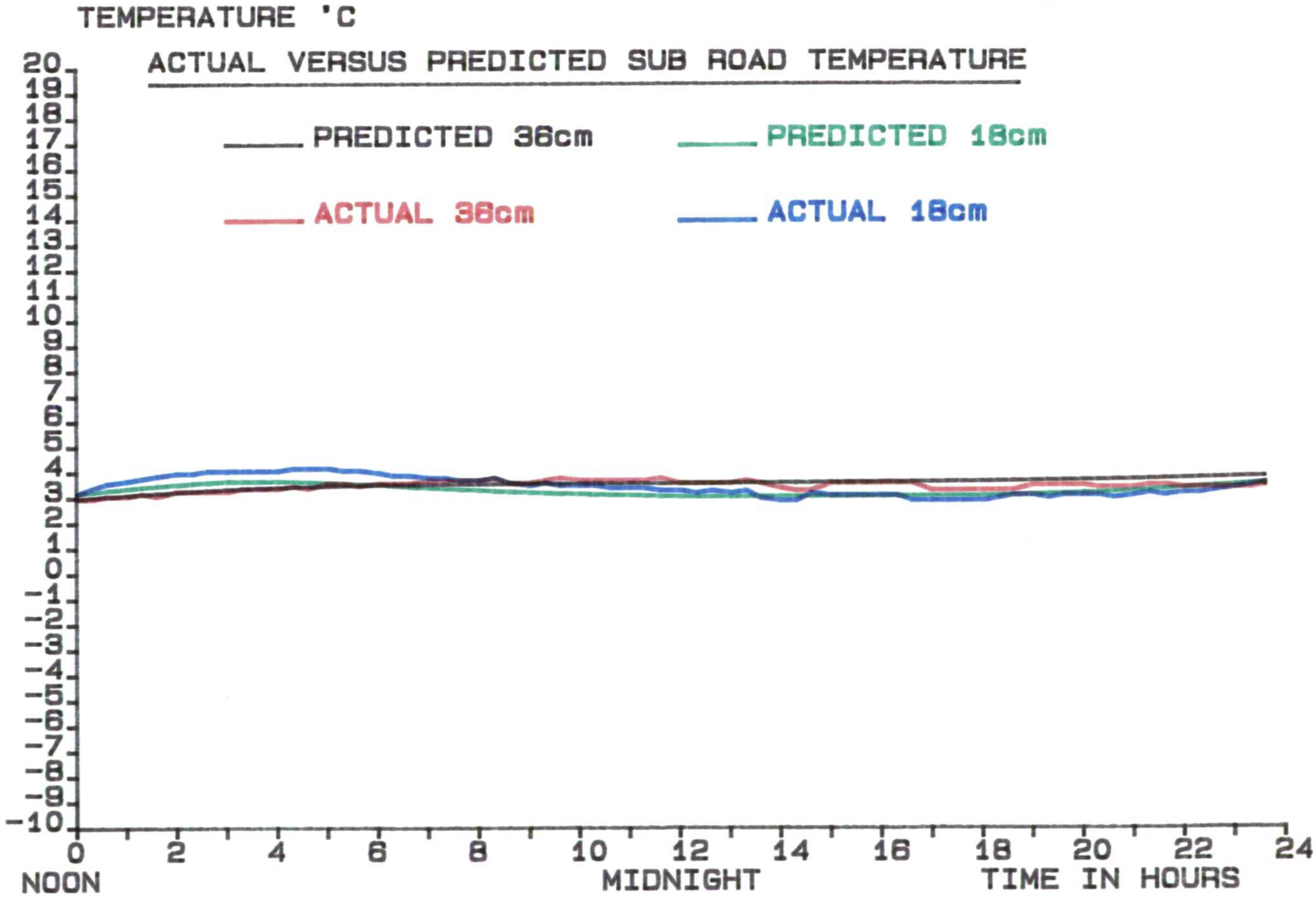
COMPUTED DATA
SAT. VAP. PRESSURE(MB)= 7.90
VAPOUR PRESSURE(MB)= 5.37
REL. HUMIDITY FRACTION = 0.68
APPROX. PRECIP. WATER(MM)= 8.7
ROAD DAMPING DEPTH(CM)= 72.
AIR DAMPING DEPTH(CM)= 4000. 4505.
AIR HEAT TRANSFER COEF.(CGS)= 0.00552 0.00686

DEC	R	T36	T18	TS	UA	D	TIME WET
-14.461	0.98	7276.2	276.4	-8.5	1077.1395.	0.5	0

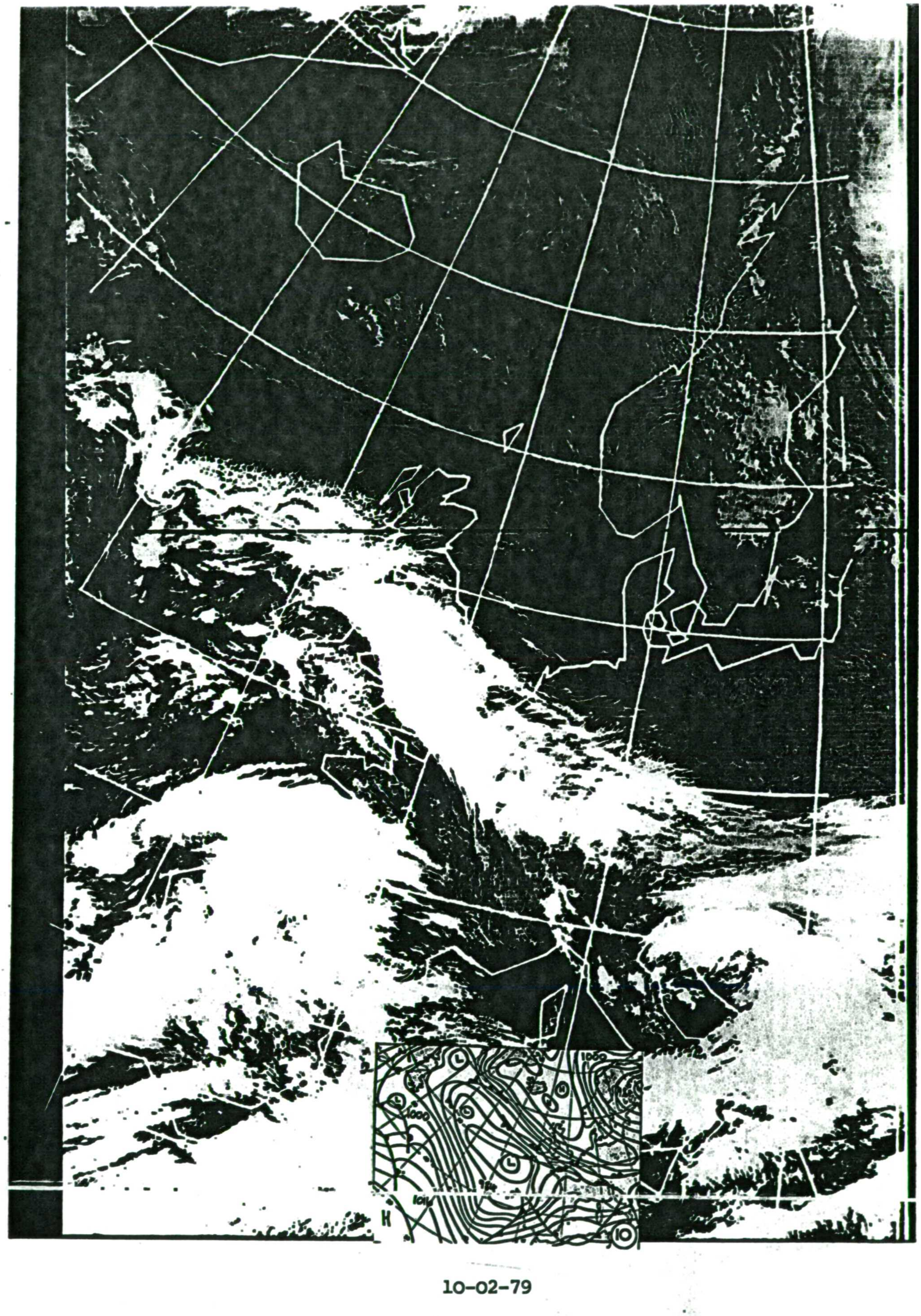
SOLAR TIME	SUN	RN	S (ALL MLY./MIN.)	H	LE	TD	TC (C.)	SUM	RI	TO	T36	Air	T18	Tslab
12.0	209.1	105.7	-20.	-87.	0.	5.50	5.09	1.	-0.00002	5.50	3.0	3.40	3.2	4.50
12.0	208.8	105.1	-19.	-86.	0.	5.29	5.09	0.	-0.00002	5.90	3.0	3.50	3.4	4.50
12.0	208.0	103.3	-19.	-85.	0.	5.18	5.07	0.	-0.00002	5.70	3.1	3.60	3.6	4.40
13.0	206.6	100.3	-18.	-83.	0.	5.11	5.04	0.	-0.00002	5.80	3.1	3.60	3.7	4.60
13.0	204.6	96.1	-17.	-80.	0.	5.06	5.01	0.	-0.00002	5.80	3.2	3.80	3.8	5.00
13.0	202.0	90.5	-15.	-76.	0.	5.01	4.96	0.	-0.00002	6.00	3.1	3.60	3.9	4.80
14.0	198.6	83.6	-13.	-71.	0.	4.95	4.89	0.	-0.00002	5.70	3.3	3.60	4.0	4.50
14.0	194.4	75.3	-11.	-65.	0.	4.88	4.82	0.	-0.00001	5.60	3.3	3.50	4.0	4.30
14.0	189.1	65.5	-8.	-58.	0.	4.80	4.72	0.	-0.00001	5.40	3.3	3.40	4.1	4.30
15.0	182.5	52.7	14.	-67.	0.	4.47	4.14	0.	-0.00001	5.30	3.3	3.30	4.1	3.90
15.0	174.0	39.9	11.	-52.	0.	4.21	3.95	0.	-0.00001	5.30	3.4	3.30	4.1	4.10
15.0	162.5	25.4	12.	-38.	0.	4.00	3.78	0.	-0.00001	5.40	3.4	3.20	4.1	4.00
16.0	145.5	9.2	15.	-24.	0.	3.80	3.61	0.	-0.00001	4.90	3.4	3.00	4.1	3.70
16.0	114.7	-9.0	17.	-9.	0.	3.61	3.41	0.	0.00000	4.70	3.5	3.00	4.2	3.40
16.0	31.6	-29.5	21.	8.	0.	3.40	3.20	0.	0.00000	4.40	3.4	2.80	4.2	3.30
17.0	0.0	-33.2	18.	15.	0.	3.26	3.12	0.	0.00000	4.50	3.6	2.60	4.2	2.60
17.0	0.0	-33.2	16.	17.	0.	3.17	3.09	0.	0.00000	4.20	3.6	2.50	4.1	2.50
17.0	0.0	-33.1	14.	19.	0.	3.12	3.06	0.	0.00000	3.50	3.5	2.20	4.1	2.10
18.0	0.0	-33.7	32.	1.	0.	2.85	2.58	0.	0.00000	3.60	3.6	2.20	4.0	2.00
18.0	0.0	-33.6	25.	8.	0.	2.68	2.50	0.	0.00000	3.20	3.6	2.10	3.9	1.80
18.0	0.0	-33.5	22.	11.	0.	2.57	2.46	0.	0.00000	3.40	3.6	2.10	3.9	1.80
19.0	0.0	-33.4	20.	13.	0.	2.51	2.44	0.	0.00000	3.20	3.7	2.10	3.8	1.90
19.0	0.0	-33.4	19.	14.	0.	2.46	2.42	0.	0.00000	3.10	3.7	2.10	3.8	1.80
19.0	0.0	-33.4	17.	16.	0.	2.43	2.40	0.	0.00000	3.10	3.7	2.20	3.7	2.00
20.0	0.0	-33.3	16.	17.	0.	2.41	2.39	0.	0.00000	3.20	3.7	2.00	3.7	1.50
20.0	0.0	-33.3	15.	18.	0.	2.40	2.38	0.	0.00000	3.00	3.8	2.30	3.8	1.90
20.0	0.0	-33.3	14.	18.	0.	2.38	2.37	0.	0.00000	2.70	3.6	2.00	3.6	1.50
21.0	0.0	-33.3	14.	19.	0.	2.37	2.36	0.	0.00000	2.60	3.6	2.10	3.5	1.50
										2.60	3.7	2.20	3.6	1.40
21.0	0.0	-33.2	13.	20.	0.	2.36	2.35	0.	0.00000	2.70	3.8	2.50	3.5	1.60
21.0	0.0	-33.2	12.	20.	0.	2.35	2.34	0.	0.00000	2.70	3.7	2.30	3.5	1.60
22.0	0.0	-33.2	12.	21.	0.	2.34	2.34	0.	0.00000	2.80	3.7	2.40	3.5	1.60
22.0	0.0	-33.2	11.	21.	0.	2.34	2.33	0.	0.00000	2.70	3.7	2.20	3.4	1.70
22.0	0.0	-33.2	11.	22.	0.	2.33	2.33	0.	0.00000	2.50	3.7	2.10	3.4	1.60
23.0	0.0	-33.2	11.	22.	0.	2.33	2.32	0.	0.00000	2.50	3.7	2.10	3.4	1.60
23.0	0.0	-33.2	10.	22.	0.	2.32	2.32	0.	0.00000	2.50	3.8	2.30	3.3	1.60
23.0	0.0	-33.2	10.	23.	0.	2.32	2.31	0.	0.00000	2.40	3.6	2.10	3.3	1.50
0.0	0.0	-33.1	1.	32.	0.	2.42	2.53	0.	0.00000	2.40	3.6	2.30	3.2	1.60
0.0	0.0	-33.1	3.	30.	0.	2.49	2.55	0.	0.00000	2.50	3.6	2.20	3.3	1.50
0.0	0.0	-33.2	4.	29.	0.	2.52	2.56	0.	0.00000	2.50	3.6	2.30	3.2	1.70
1.0	0.0	-33.2	4.	28.	0.	2.54	2.56	0.	0.00000	2.50	3.7	2.30	3.3	1.70
1.0	0.0	-33.2	4.	28.	0.	2.55	2.56	0.	0.00000	2.50	3.6	2.40	3.0	1.80
1.0	0.0	-33.2	5.	28.	0.	2.56	2.57	0.	0.00000	2.20	3.4	2.10	2.9	1.30
2.0	0.0	-33.2	5.	28.	0.	2.56	2.57	0.	0.00000	2.20	3.3	2.20	2.9	1.40
2.0	0.0	-33.2	5.	28.	0.	2.57	2.57	0.	0.00000	2.20	3.3	2.10	3.2	1.50
2.0	0.0	-33.2	5.	28.	0.	2.57	2.57	0.	0.00000	2.50	3.6	2.40	3.1	1.70
3.0	0.0	-33.2	5.	28.	0.	2.57	2.57	0.	0.00000	2.50	3.6	2.40	3.1	1.80
3.0	0.0	-33.2	5.	28.	0.	2.57	2.57	0.	0.00000	2.50	3.6	2.40	3.1	1.80
3.0	0.0	-33.2	5.	28.	0.	2.57	2.57	0.	0.00000	2.50	3.6	2.50	3.1	1.90
4.0	0.0	-33.2	5.	28.	0.	2.57	2.57	0.	0.00000	2.50	3.6	2.60	3.1	1.90
4.0	0.0	-33.2	5.	28.	0.	2.57	2.57	0.	0.00000	2.60	3.6	2.80	2.9	2.00
4.0	0.0	-33.2	5.	28.	0.	2.57	2.57	0.	0.00000	2.30	3.3	2.60	2.9	1.80
5.0	0.0	-33.2	5.	28.	0.	2.57	2.57	0.	0.00000	2.40	3.3	2.60	2.9	1.80
5.0	0.0	-33.2	5.	28.	0.	2.57	2.57	0.	0.00000	2.40	3.3	2.60	2.9	1.70
5.0	0.0	-33.2	5.	28.	0.	2.57	2.57	0.	0.00000	2.40	3.3	2.50	2.9	1.80
6.0	0.0	-32.5	-7.	39.	0.	2.72	2.86	0.	0.00000	2.40	3.3	2.60	3.0	1.90
6.0	0.0	-32.6	-3.	35.	0.	2.80	2.89	0.	0.00000	2.40	3.3	2.50	3.1	1.80
6.0	0.0	-32.6	-2.	34.	0.	2.86	2.91	0.	0.00000	2.60	3.5	2.70	3.1	1.90
7.0	0.0	-32.7	-1.	33.	0.	2.89	2.92	0.	0.00000	2.60	3.5	2.70	3.0	2.10
7.0	39.4	-27.6	-2.	29.	0.	2.92	2.96	0.	0.00000					
7.0	117.3	-7.0	-7.	14.	0.	3.02	3.11	0.	0.00000	2.60	3.5	2.60	3.1	2.00
8.0	146.9	11.2	-10.	-2.	0.	3.14	3.27	0.	0.00000	2.70	3.5	2.70	3.1	2.10
8.0	163.5	27.5	-12.	-16.	0.	3.28	3.41	0.	0.00000	2.80	3.4	2.60	3.1	2.10
8.0	174.8	42.1	-14.	-29.	0.	3.41	3.54	0.	0.00000	3.50	3.4	2.70	3.0	2.30
9.0	183.2	55.1	-15.	-41.	0.	3.53	3.66	0.	0.00000	3.10	3.4	2.70	3.1	2.40
9.0	189.7	66.4	-16.	-51.	0.	3.65	3.77	0.	-0.00001	3.40	3.5	2.70	3.2	2.40
9.0	194.9	76.2	-16.	-61.	0.	3.76	3.86	0.	-0.00001	3.70	3.5	[illegible]	[illegible]	[illegible]
10.0	199.1	84.5	-16.	-69.	0.	[illegible]	[illegible]	[illegible]	[illegible]	3.90	3.4	3.00	3.2	3.30
[illegible]	[illegible]	91.4	-16.	-76.	0.	3.94	4.02	0.	-0.00001	4.20	3.4	3.10	3.2	3.60
10.0	205.1	96.9	-16.	-82.	0.	4.01	4.08	0.	-0.00001	5.30	3.4	3.20	3.3	4.00
11.0	207.1	101.2	-15.	-87.	0.	4.07	4.13	0.	-0.00001	5.00	3.4	3.20	3.4	4.20
11.0	208.5	104.2	-14.	-90.	0.	4.12	4.17	0.	-0.00001	5.40	3.4	3.20	3.5	4.60
11.0	209.4	105.9	-13.	-93.	0.	4.16	4.19	0.	-0.00001	5.60	3.5	3.30	3.6	4.70

Model Output 09-02-79 Actuals





09-10 FEBRUARY 1979



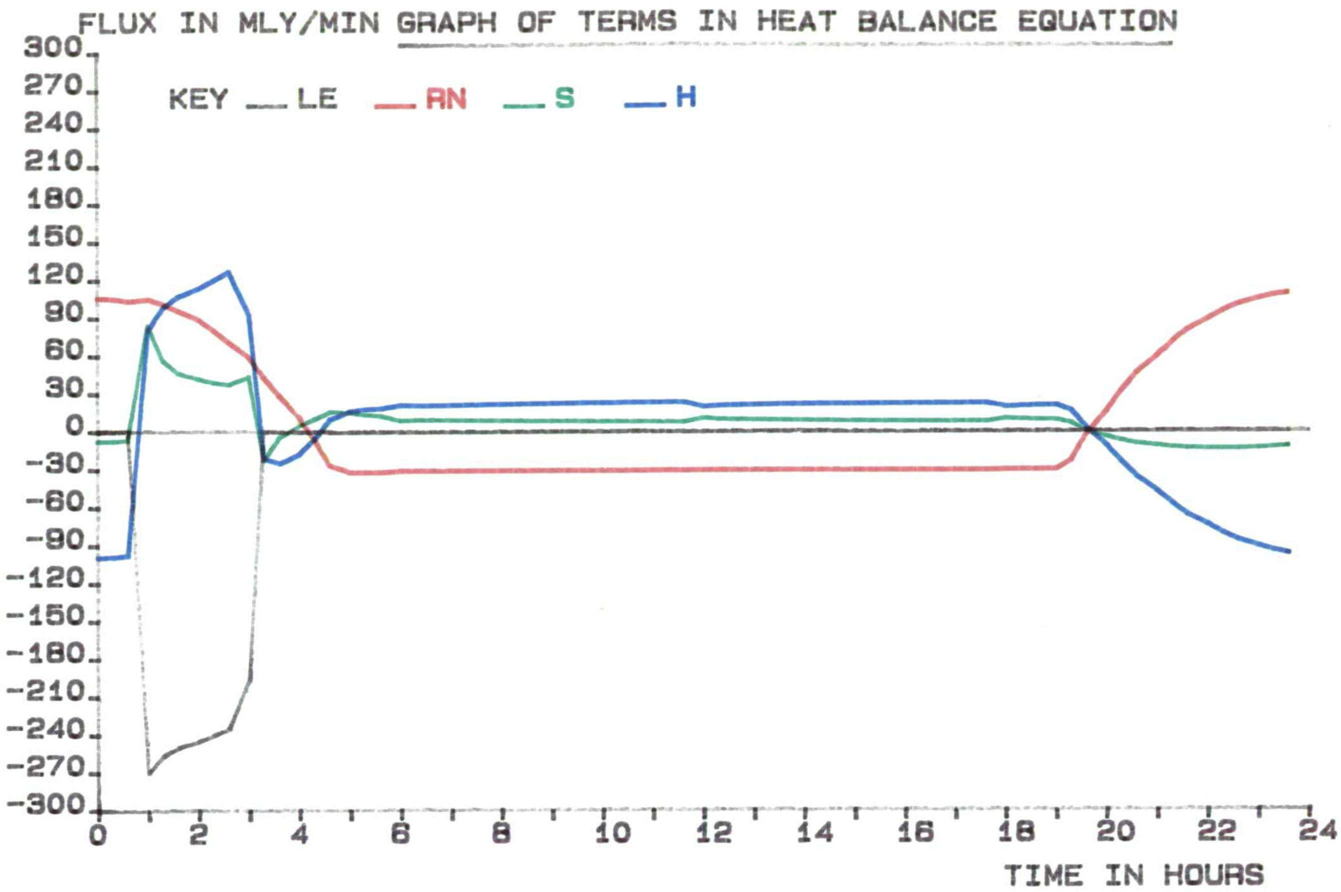
10-02-79

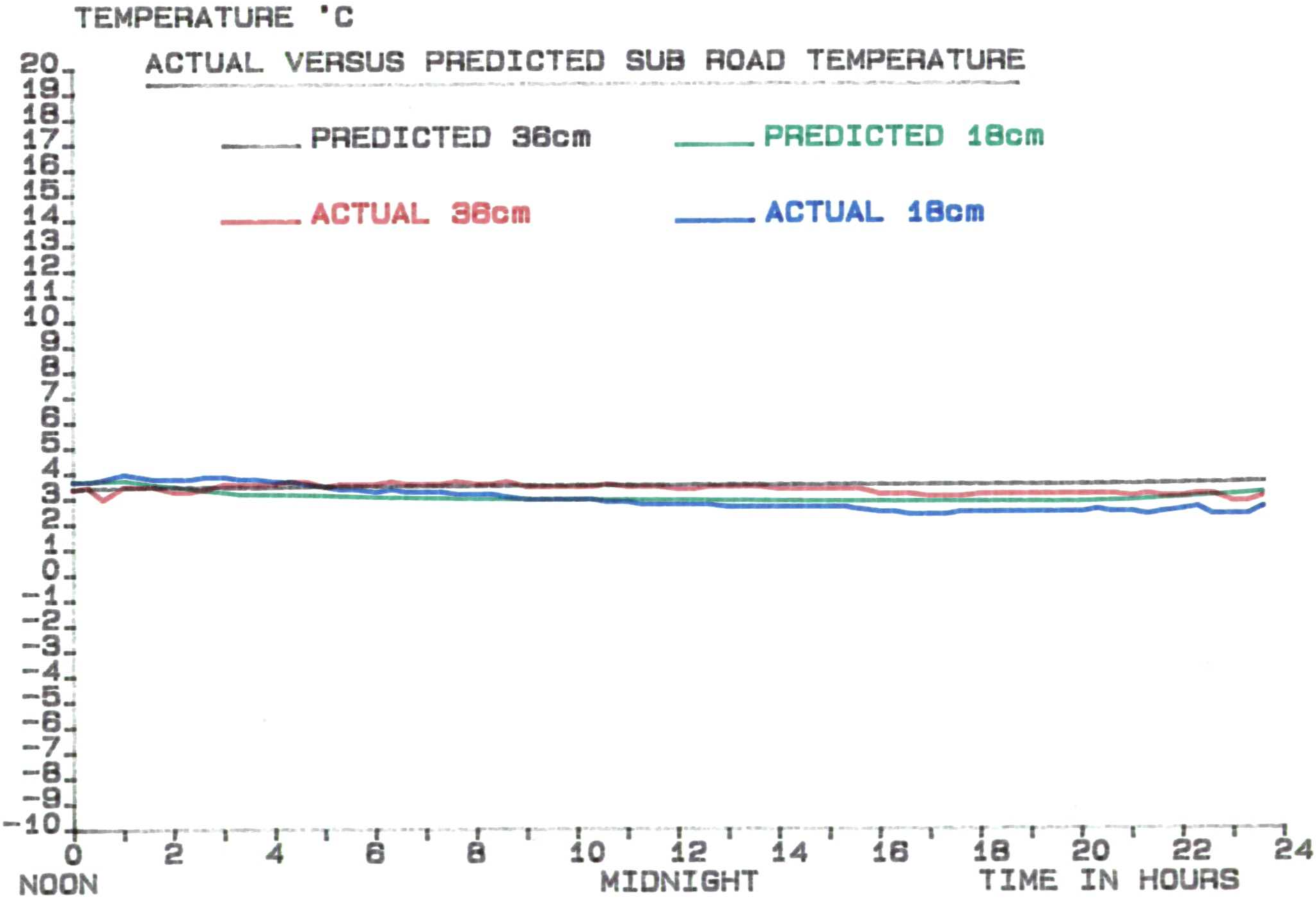
COMPUTED DATA
SAT. VAP. PRESSURE(MB)= 7.47
VAPOUR PRESSURE(MB)= 4.93
REL. HUMIDITY FRACTION = 0.66
APPROX. PRECIP. WATER(MM)= 8.0
ROAD DAMPING DEPTH(CM)= 72.
AIR DAMPING DEPTH(CM)= 4020. 3903.
AIR HEAT TRANSFER COEF.(CGS)= 0.00557 0.00528

DEC	R	T36	T18	TS	UA	D	TIME WET
-14.136	0.98	7276.6	276.9	5.7	1089.1021.	0.5	13

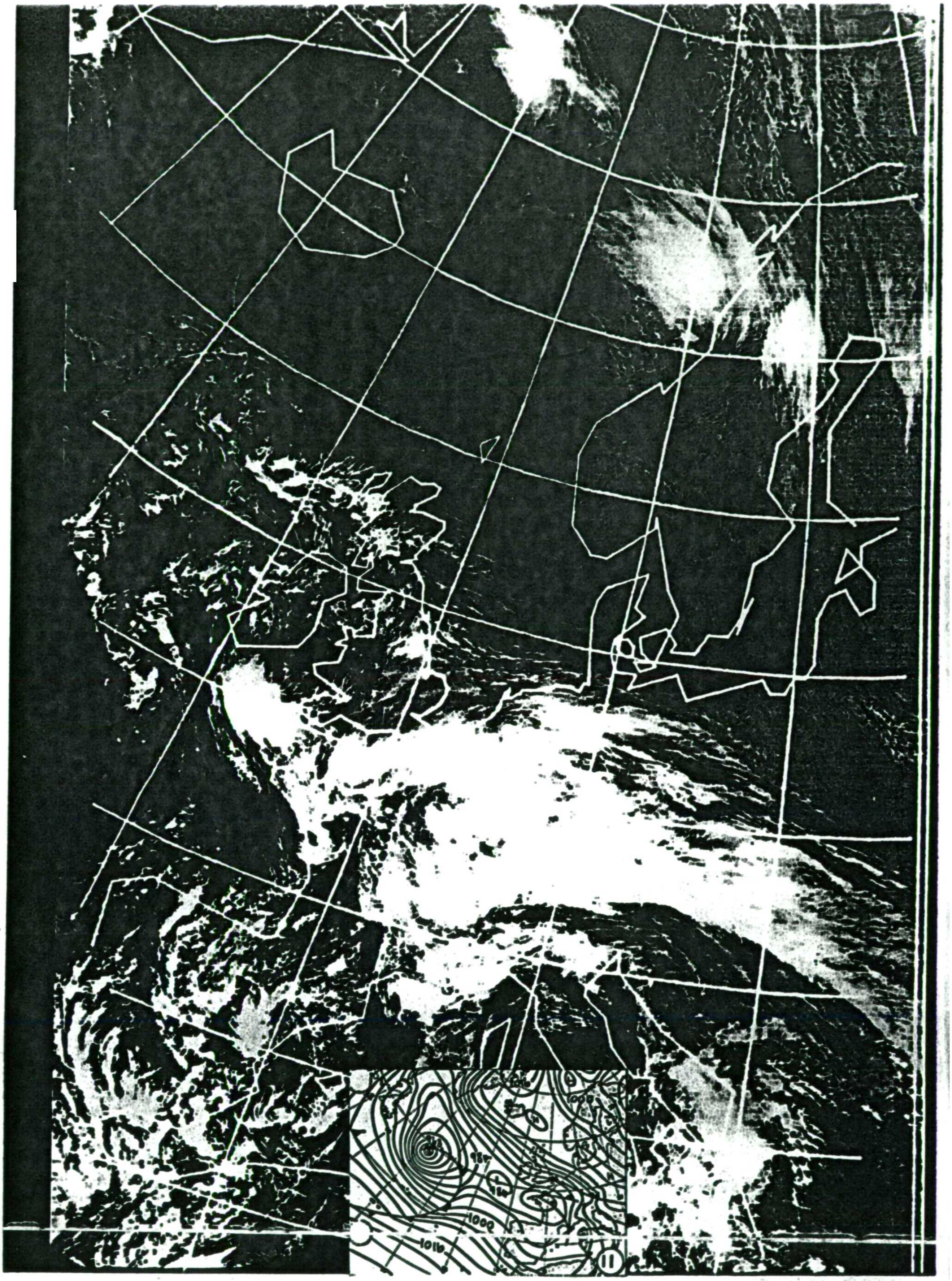
SOLAR TIME	SUN	RN	S (ALL MLY./MIN.)	H	LE	TD	TC (C.)	SUM	RI	TO	T36	Air	T18	Tslab
12.0	209.7	105.9	-8.	-99.	0.	5.70	4.43	1.	-0.00002	5.70	3.4	3.20	3.70	4.60
12.0	209.4	105.3	-7.	-98.	0.	5.06	4.43	0.	-0.00002	5.30	3.5	3.20	3.70	4.50
12.0	208.6	103.5	-7.	-97.	0.	4.74	4.41	0.	-0.00002	5.10	3.0	2.80	3.80	4.00
13.0	207.2	105.1	84.	80.	-270.	3.47	2.20	-270.	0.00002	5.90	3.5	3.20	4.00	4.60
13.0	205.2	101.3	56.	99.	-256.	2.72	1.97	-526.	0.00002	5.20	3.5	3.00	3.90	4.30
13.0	202.6	95.8	46.	107.	-249.	2.29	1.87	-775.	0.00002	4.40	3.5	2.80	3.80	3.70
14.0	199.2	89.0	42.	114.	-244.	2.04	1.79	-1020.	0.00002	3.90	3.3	2.30	3.80	2.90
14.0	195.0	80.7	39.	120.	-240.	1.87	1.71	-1259.	0.00003	3.50	3.3	2.30	3.80	2.40
14.0	189.9	71.0	37.	127.	-235.	1.75	1.62	-1494.	0.00003	3.20	3.4	2.30	3.90	2.30
15.0	183.4	59.4	44.	93.	-196.	1.55	1.35	-1690.	0.00002	3.30	3.6	2.40	3.90	2.50
15.0	175.1	43.4	-23.	-21.	0.	2.16	2.77	-1690.	0.00000	3.30	3.6	2.40	3.80	2.40
15.0	163.9	28.4	-4.	-25.	0.	2.48	2.81	-1690.	-0.00001	3.10	3.6	2.30	3.80	2.20
16.0	147.6	12.2	4.	-17.	0.	2.60	2.72	-1690.	0.00000	2.90	3.6	2.20	3.70	2.00
16.0	118.7	-6.0	10.	-5.	0.	2.58	2.56	-1690.	0.00000	2.80	3.7	2.10	3.70	1.80
16.0	43.9	-26.5	16.	10.	0.	2.48	2.37	-1690.	0.00000	2.70	3.7	2.10	3.60	1.80
17.0	0.0	-32.2	15.	16.	0.	2.39	2.30	-1690.	0.00000	2.50	3.5	2.00	3.50	1.70
17.0	0.0	-32.2	13.	18.	0.	2.33	2.28	-1690.	0.00000	2.40	3.6	1.90	3.40	1.40
17.0	0.0	-32.1	13.	19.	0.	2.30	2.27	-1690.	0.00000	2.30	3.6	1.90	3.40	1.40
18.0	0.0	-30.9	9.	21.	0.	2.32	2.33	-1690.	0.00000	2.40	3.6	1.90	3.30	1.60
18.0	0.0	-30.9	9.	21.	0.	2.33	2.34	-1690.	0.00000	2.40	3.7	2.10	3.40	1.60
18.0	0.0	-30.9	9.	21.	0.	2.33	2.34	-1690.	0.00000	2.30	3.6	2.20	3.30	1.50
19.0	0.0	-30.9	9.	21.	0.	2.33	2.34	-1690.	0.00000	2.30	3.6	2.20	3.30	1.50
19.0	0.0	-30.9	9.	22.	0.	2.33	2.33	-1690.	0.00000	2.30	3.6	2.20	3.30	1.70
19.0	0.0	-30.9	9.	22.	0.	2.33	2.33	-1690.	0.00000	2.40	3.7	2.30	3.20	1.60
20.0	0.0	-30.9	8.	22.	0.	2.33	2.33	-1690.	0.00000	2.30	3.6	2.40	3.20	1.60
20.0	0.0	-30.9	8.	22.	0.	2.33	2.33	-1690.	0.00000	2.30	3.6	2.50	3.20	1.80
20.0	0.0	-30.9	8.	22.	0.	2.33	2.32	-1690.	0.00000	2.40	3.7	2.50	3.10	1.60
21.0	0.0	-30.9	8.	22.	0.	2.33	2.32	-1690.	0.00000	2.20	3.5	2.40	3.00	1.50
										2.20	3.5	2.50	3.00	1.50
21.0	0.0	-30.9	8.	22.	0.	2.32	2.32	-1690.	0.00000	2.10	3.5	2.30	3.00	1.20
21.0	0.0	-30.9	8.	23.	0.	2.32	2.32	-1690.	0.00000	1.90	3.5	2.10	3.00	1.30
22.0	0.0	-30.9	8.	23.	0.	2.32	2.32	-1690.	0.00000	1.70	3.5	2.00	3.00	1.00
22.0	0.0	-30.9	7.	23.	0.	2.32	2.32	-1690.	0.00000	1.80	3.6	2.00	2.90	1.10
22.0	0.0	-30.9	7.	23.	0.	2.32	2.32	-1690.	0.00000	1.40	3.5	1.90	2.90	0.80
23.0	0.0	-30.9	7.	23.	0.	2.32	2.32	-1690.	0.00000	1.50	3.5	2.00	2.80	0.90
23.0	0.0	-30.9	7.	23.	0.	2.32	2.32	-1690.	0.00000	1.70	3.5	2.10	2.80	1.10
23.0	0.0	-30.9	7.	23.	0.	2.32	2.31	-1690.	0.00000	1.70	3.4	2.10	2.80	1.00
0.0	0.0	-30.8	10.	20.	0.	2.27	2.23	-1690.	0.00000	1.70	3.4	2.20	2.80	1.10
0.0	0.0	-30.8	10.	21.	0.	2.25	2.22	-1690.	0.00001	1.80	3.5	2.30	2.80	1.20
0.0	0.0	-30.8	9.	21.	0.	2.23	2.21	-1690.	0.00001	1.70	3.5	2.20	2.70	1.00
1.0	0.0	-30.8	9.	21.	0.	2.22	2.21	-1690.	0.00001	1.80	3.5	2.40	2.70	1.20
1.0	0.0	-30.8	9.	21.	0.	2.21	2.21	-1690.	0.00001	1.80	3.5	2.30	2.70	1.20
1.0	0.0	-30.8	8.	22.	0.	2.21	2.21	-1690.	0.00001	1.70	3.4	2.20	2.70	1.20
2.0	0.0	-30.7	8.	22.	0.	2.21	2.20	-1690.	0.00001	1.70	3.4	2.20	2.70	1.30
2.0	0.0	-30.7	8.	22.	0.	2.21	2.20	-1690.	0.00001	1.80	3.4	2.20	2.70	1.30
2.0	0.0	-30.7	8.	22.	0.	2.20	2.20	-1690.	0.00001	1.80	3.4	2.20	2.70	1.30
3.0	0.0	-30.7	8.	22.	0.	2.20	2.20	-1690.	0.00001	1.80	3.4	2.20	2.70	1.30
3.0	0.0	-30.7	8.	22.	0.	2.20	2.20	-1690.	0.00001	1.70	3.4	2.20	2.60	1.30
3.0	0.0	-30.7	8.	22.	0.	2.20	2.20	-1690.	0.00001	1.60	3.2	2.00	2.50	1.20
4.0	0.0	-30.7	8.	22.	0.	2.20	2.20	-1690.	0.00001	1.60	3.2	2.00	2.50	1.20
4.0	0.0	-30.7	8.	22.	0.	2.20	2.20	-1690.	0.00001	1.60	3.2	2.00	2.40	1.30
4.0	0.0	-30.7	8.	22.	0.	2.20	2.20	-1690.	0.00001	1.50	3.1	1.80	2.40	1.00
5.0	0.0	-30.7	8.	22.	0.	2.20	2.20	-1690.	0.00001	1.60	3.1	1.80	2.40	1.10
5.0	0.0	-30.7	8.	22.	0.	2.20	2.19	-1690.	0.00001	1.50	3.1	1.80	2.50	1.10
5.0	0.0	-30.7	8.	23.	0.	2.19	2.19	-1690.	0.00001	1.70	3.2	2.00	2.50	1.30
6.0	0.0	-30.2	10.	19.	0.	2.16	2.13	-1690.	0.00000	1.70	3.2	2.00	2.50	1.20
6.0	0.0	-30.2	9.	20.	0.	2.14	2.13	-1690.	0.00001	1.70	3.2	2.00	2.50	1.30
6.0	0.0	-30.2	9.	20.	0.	2.13	2.12	-1690.	0.00001	1.70	3.2	1.80	2.50	1.30
7.0	0.0	-30.2	9.	21.	0.	2.13	2.12	-1690.	0.00001	1.70	3.2	1.80	2.50	1.30
7.0	51.1	-23.2	6.	16.	0.	2.15	2.18	-1690.	0.00000					
7.0	121.1	-2.7	0.	2.	0.	2.25	2.36	-1690.	0.00000	1.70	3.2	1.80	2.50	1.20
8.0	148.9	15.4	-5.	-11.	0.	2.40	2.54	-1690.	0.00000	1.80	3.2	1.60	2.50	1.20
8.0	164.9	31.5	-8.	-24.	0.	2.55	2.71	-1690.	-0.00001	1.80	3.2	1.50	2.60	1.20
8.0	175.8	46.0	-10.	-36.	0.	2.71	2.87	-1690.	-0.00001	1.80	3.2	1.60	2.50	1.20
9.0	184.0	58.8	-12.	-48.	0.	2.86	3.02	-1690.	-0.00001	1.60	3.1	1.80	2.50	1.20
9.0	190.5	70.1	-13.	-58.	0.	3.01	3.15	-1690.	-0.00001	2.00	3.2	2.00	2.40	1.30
9.0	195.6	79.7	-14.	-66.	0.	3.13	3.26	-1690.	-0.00002	2.10	3.1	2.00	2.50	1.40
10.0	199.8	88.0	-14.	-74.	0.	3.25	3.37	-1690.	-0.00002	2.30	3.1	2.20	2.60	1.80
[illegible]	[illegible]	[illegible]	[illegible]	-81.	0.	3.35	3.45	-1690.	-0.00002	[illegible]	3.2	2.30	2.70	2.00
10.0	205.7	100.3	-14.	-87.	0.	3.44	3.53	-1690.	-0.00002	2.70	3.2	2.30	2.40	2.10
11.0	207.7	104.5	-14.	-91.	0.	3.52	3.59	-1690.	-0.00002	2.40	2.9	2.00	2.40	1.70
11.0	209.1	107.4	-13.	-95.	0.	3.58	3.64	-1690.	-0.00002	2.90	2.9	2.10	2.40	2.00
11.0	209.9	109.2	-12.	-98.	0.	3.62	3.67	-1690.	-0.00002	2.90	3.1	2.20	2.70	2.30

Model Output 10-02-79 Actuals





10-11 FEBRUARY 1979



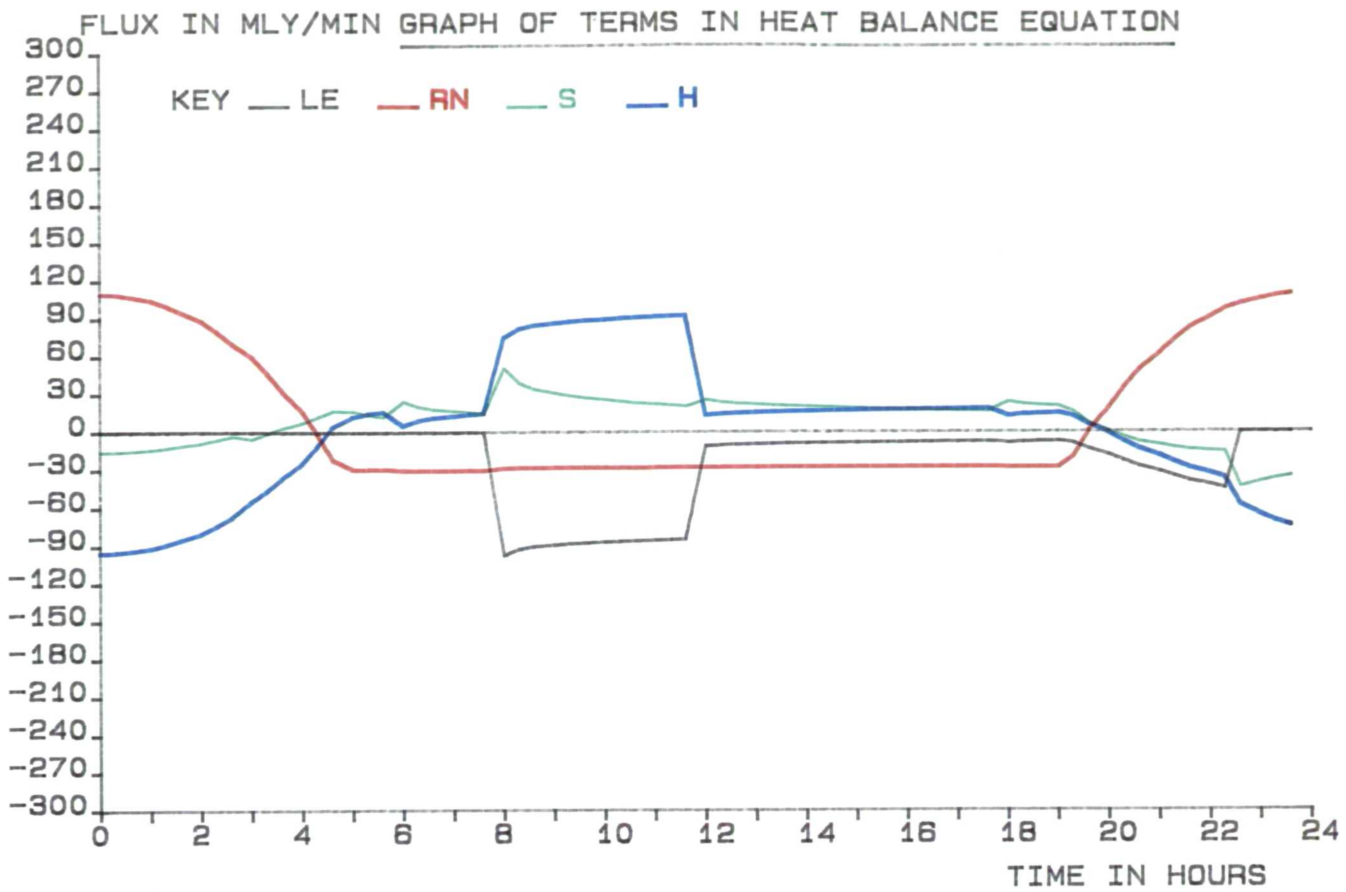
11-02-79

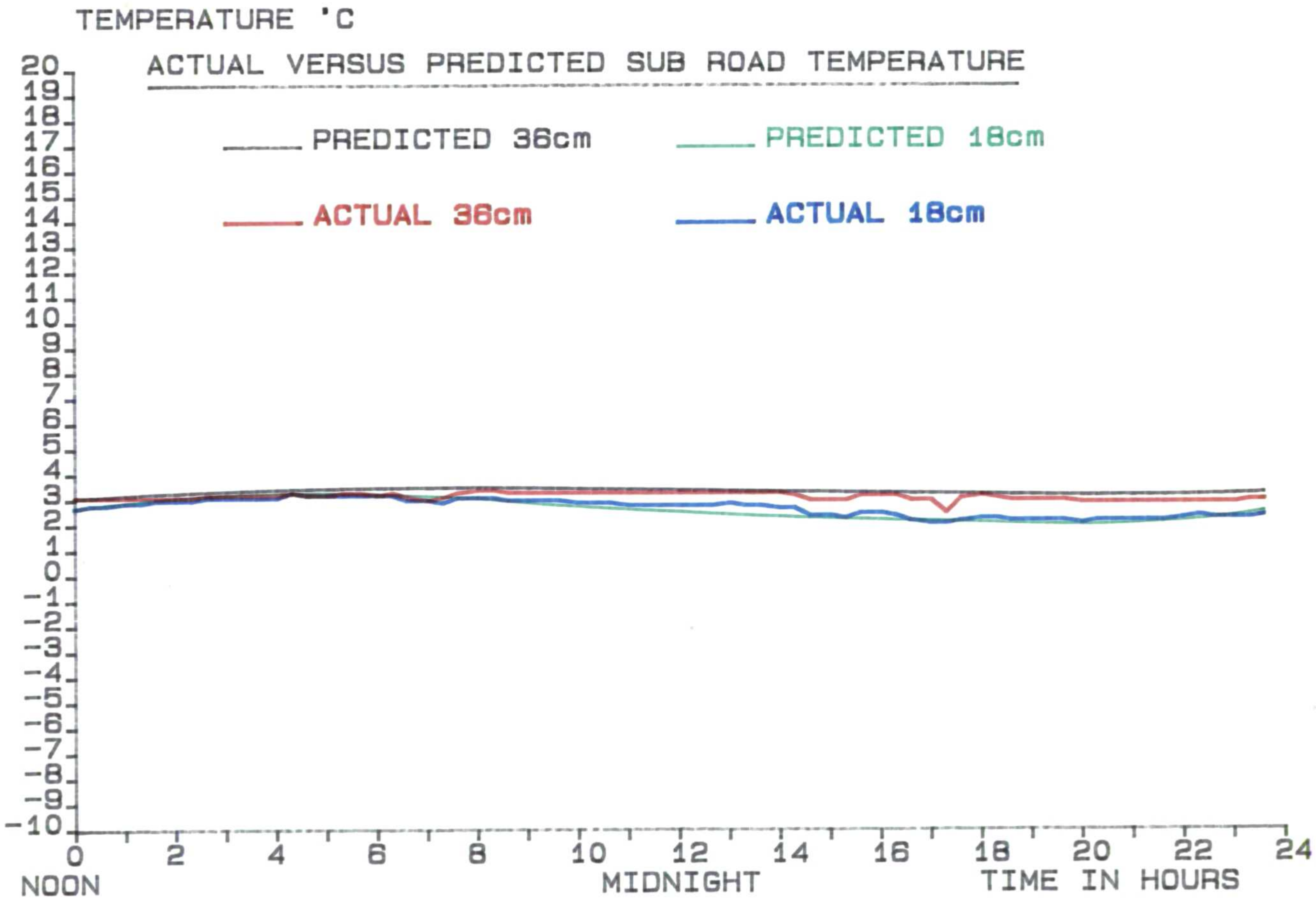
COMPUTED DATA
SAT. VAP. PRESSURE(MB)= 7.26
VAPOUR PRESSURE(MB)= 5.95
REL. HUMIDITY FRACTION = 0.82
APPROX. PRECIP. WATER(MM)= 9.5
ROAD DAMPING DEPTH(CM)= 72.
AIR DAMPING DEPTH(CM)= 3623. 2218.
AIR HEAT TRANSFER COEF.(CGS)= 0.00461 0.00190

DEC	R	T36	T18	TS	UA	D	TIME WET
-13.806	0.987	276.3	275.9	3.3	868. 296.	0.5	20

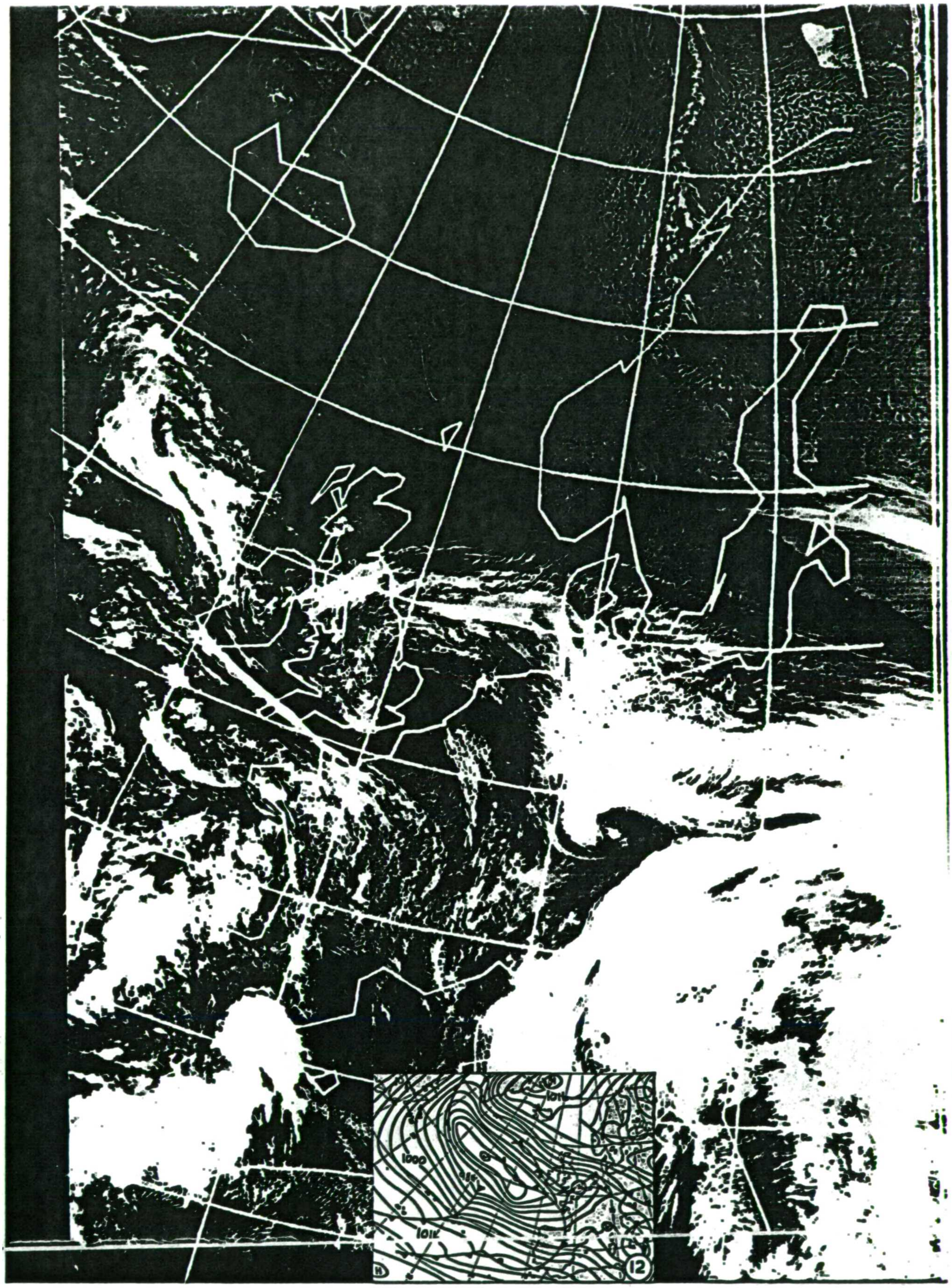
SOLAR TIME	SUN	RN	S (ALL MLY./MIN.)	H	LE	TD	TC (C.)	SUM	RI	TO	T36	Air	T18	Tslab
12.0	210.2	109.6	-15.	-95.	0.	3.30	4.19	1.	-0.00004	3.30	3.1	2.50	2.70	2.60
12.0	209.9	109.0	-15.	-94.	0.	3.74	4.18	0.	-0.00004	3.60	3.1	2.40	2.80	2.50
12.0	209.1	107.2	-15.	-93.	0.	3.95	4.17	0.	-0.00004	3.60	3.1	2.50	2.80	2.50
13.0	207.7	104.3	-14.	-91.	0.	4.05	4.14	0.	-0.00004	3.40	3.1	2.50	2.90	2.50
13.0	205.8	100.1	-12.	-89.	0.	4.07	4.10	0.	-0.00003	3.40	3.1	2.40	2.90	2.50
13.0	203.2	94.6	-10.	-85.	0.	4.06	4.04	0.	-0.00003	3.40	3.1	2.40	3.00	2.60
14.0	199.9	87.8	-8.	-80.	0.	4.01	3.97	0.	-0.00003	3.50	3.1	2.30	3.00	2.40
14.0	195.7	79.6	-6.	-74.	0.	3.95	3.88	0.	-0.00003	3.40	3.1	2.40	3.00	2.60
14.0	190.6	69.9	-3.	-68.	0.	3.86	3.78	0.	-0.00003	3.40	3.2	2.30	3.10	2.30
15.0	184.3	59.3	-5.	-55.	0.	3.82	3.79	0.	-0.00002	3.30	3.2	2.40	3.10	2.40
15.0	176.1	46.5	-1.	-47.	0.	3.74	3.66	0.	-0.00002	3.30	3.2	2.50	3.10	2.30
15.0	165.3	32.1	4.	-36.	0.	3.63	3.51	0.	-0.00001	3.40	3.2	2.70	3.10	2.70
16.0	149.6	16.0	8.	-25.	0.	3.48	3.33	0.	-0.00001	3.30	3.2	2.70	3.10	2.40
16.0	122.5	-1.9	12.	-11.	0.	3.30	3.13	0.	0.00000	3.40	3.3	2.80	3.30	2.50
16.0	55.3	-22.2	17.	4.	0.	3.10	2.90	0.	0.00000	3.30	3.2	2.70	3.20	2.30
17.0	0.0	-29.8	17.	12.	0.	2.94	2.77	0.	0.00000	3.20	3.2	2.60	3.20	2.10
17.0	0.0	-29.7	14.	15.	0.	2.84	2.74	0.	0.00001	3.20	3.3	2.70	3.20	2.00
17.0	0.0	-29.7	13.	16.	0.	2.78	2.71	0.	0.00001	3.20	3.3	2.70	3.20	2.20
18.0	0.0	-30.8	25.	5.	0.	2.58	2.38	0.	0.00000	3.00	3.2	2.60	3.20	1.90
18.0	0.0	-30.6	20.	10.	0.	2.45	2.32	0.	0.00000	3.00	3.3	2.50	3.20	2.00
18.0	0.0	-30.6	18.	12.	0.	2.37	2.29	0.	0.00000	2.80	3.1	2.40	3.00	1.70
19.0	0.0	-30.5	17.	13.	0.	2.32	2.26	0.	0.00001	2.40	3.0	2.10	3.00	1.30
19.0	0.0	-30.5	16.	14.	0.	2.28	2.25	0.	0.00001	2.30	3.1	1.90	2.90	1.30
19.0	0.0	-30.5	15.	15.	0.	2.26	2.24	0.	0.00001	2.20	3.3	1.90	3.10	1.20
20.0	0.0	-28.6	51.	75.	-97.	1.80	1.33	-97.	0.00003	2.30	3.4	2.10	3.10	1.30
20.0	0.0	-28.4	39.	82.	-92.	1.51	1.23	-189.	0.00003	2.30	3.4	2.20	3.10	1.40
20.0	0.0	-28.3	34.	85.	-90.	1.35	1.19	-280.	0.00003	2.40	3.3	2.40	3.00	1.50
21.0	0.0	-28.3	31.	86.	-89.	1.26	1.16	-369.	0.00003	2.30	3.3	2.30	3.00	1.40
										2.30	3.3	2.10	3.00	1.40
21.0	0.0	-28.2	29.	88.	-88.	1.20	1.14	-457.	0.00003	2.30	3.3	2.10	3.00	1.40
21.0	0.0	-28.2	27.	89.	-87.	1.16	1.13	-544.	0.00003	2.20	3.3	2.00	2.90	1.40
22.0	0.0	-28.2	25.	89.	-87.	1.14	1.12	-631.	0.00003	2.20	3.3	2.00	2.90	1.30
22.0	0.0	-28.2	24.	90.	-86.	1.12	1.10	-717.	0.00004	2.20	3.3	1.90	2.90	1.30
22.0	0.0	-28.1	23.	91.	-86.	1.11	1.09	-803.	0.00004	2.20	3.3	2.00	2.80	1.40
23.0	0.0	-28.1	22.	91.	-85.	1.10	1.09	-888.	0.00004	2.20	3.3	1.90	2.80	1.40
23.0	0.0	-28.1	21.	92.	-85.	1.09	1.08	-973.	0.00004	2.20	3.3	1.90	2.80	1.40
23.0	0.0	-28.1	20.	92.	-85.	1.08	1.07	-1058.	0.00004	2.20	3.3	1.90	2.80	1.40
0.0	0.0	-28.1	25.	14.	-11.	1.00	0.92	-1069.	0.00010	2.10	3.3	1.90	2.80	1.30
0.0	0.0	-28.1	24.	15.	-10.	0.94	0.88	-1079.	0.00011	2.10	3.3	1.80	2.80	1.20
0.0	0.0	-28.0	23.	15.	-10.	0.90	0.86	-1089.	0.00011	1.90	3.3	1.80	2.90	1.20
1.0	0.0	-28.0	22.	16.	-10.	0.87	0.85	-1099.	0.00012	1.70	3.3	1.60	2.80	1.00
1.0	0.0	-28.0	21.	16.	-9.	0.85	0.83	-1108.	0.00012	1.40	3.3	1.40	2.80	0.60
1.0	0.0	-27.9	21.	16.	-9.	0.84	0.82	-1117.	0.00012	1.40	3.3	1.30	2.70	0.80
2.0	0.0	-27.9	20.	17.	-9.	0.82	0.81	-1126.	0.00012	1.40	3.2	1.30	2.70	0.70
2.0	0.0	-27.9	20.	17.	-9.	0.81	0.80	-1135.	0.00013	1.40	3.0	1.20	2.40	0.70
2.0	0.0	-27.9	19.	17.	-8.	0.80	0.79	-1143.	0.00013	1.00	3.0	0.80	2.40	0.40
3.0	0.0	-27.9	19.	17.	-8.	0.79	0.78	-1151.	0.00013	0.80	3.0	0.80	2.30	0.40
3.0	0.0	-27.8	18.	18.	-8.	0.78	0.77	-1160.	0.00013	0.70	3.2	0.60	2.50	0.50
3.0	0.0	-27.8	18.	18.	-8.	0.78	0.77	-1168.	0.00013	0.80	3.2	1.00	2.50	0.60
4.0	0.0	-27.8	18.	18.	-8.	0.77	0.76	-1176.	0.00013	1.00	3.2	1.00	2.40	0.70
4.0	0.0	-27.8	17.	18.	-8.	0.76	0.76	-1183.	0.00014	1.10	3.0	0.90	2.20	0.70
4.0	0.0	-27.8	17.	18.	-8.	0.76	0.75	-1191.	0.00014	0.80	3.0	0.60	2.10	0.50
5.0	0.0	-27.8	17.	19.	-8.	0.75	0.74	-1199.	0.00014	1.00	2.5	0.70	2.10	0.50
5.0	0.0	-27.8	17.	19.	-8.	0.74	0.74	-1206.	0.00014	0.60	3.1	0.10	2.20	-0.10
5.0	0.0	-27.8	16.	19.	-7.	0.74	0.73	-1214.	0.00014	1.30	3.2	0.90	2.30	0.70
6.0	0.0	-28.3	24.	13.	-9.	0.64	0.55	-1222.	0.00010	1.40	3.1	0.80	2.30	0.80
6.0	0.0	-28.2	22.	14.	-8.	0.58	0.51	-1230.	0.00010	1.40	3.0	0.90	2.20	0.80
6.0	0.0	-28.1	21.	15.	-7.	0.53	0.49	-1237.	0.00011	1.30	3.0	0.80	2.20	0.40
7.0	0.0	-28.1	20.	15.	-7.	0.50	0.47	-1244.	0.00011	1.40	3.0	0.80	2.20	0.30
7.0	61.8	-19.2	16.	12.	-9.	0.53	0.57	-1253.	0.00009					
7.0	124.7	1.0	7.	6.	-13.	0.67	0.81	-1267.	0.00004	1.50	3.0	0.70	2.20	0.50
8.0	150.9	18.9	0.	-1.	-18.	0.86	1.06	-1285.	-0.00001	1.50	2.9	0.70	2.10	0.60
8.0	166.2	34.8	-4.	-7.	-23.	1.08	1.29	-1308.	-0.00006	1.50	2.9	0.80	2.20	0.50
8.0	176.9	49.1	-8.	-14.	-27.	1.30	1.52	-1336.	-0.00010	1.60	2.9	0.80	2.20	0.70
9.0	184.9	61.8	-11.	-19.	-31.	1.51	1.71	-1367.	-0.00014	1.70	2.9	0.60	2.20	0.60
9.0	191.2	72.8	-13.	-24.	-35.	1.70	1.90	-1402.	-0.00018	1.40	2.9	0.40	2.20	0.50
9.0	196.3	82.4	-14.	-29.	-39.	1.89	2.07	-1441.	-0.00021	1.40	[illegible]	[illegible]	[illegible]	[illegible]
10.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2.23	-1484.	-0.00025	1.50	2.9	0.50	2.30	0.50
10.0	203.7	97.2	-16.	-37.	-45.	2.21	2.36	-1529.	-0.00027	1.40	2.9	0.60	2.40	0.60
10.0	206.3	101.1	-44.	-58.	0.	2.68	3.14	-1529.	-0.00043	1.80	2.9	0.90	2.30	0.90
11.0	208.2	104.8	-40.	-66.	0.	3.05	3.43	-1529.	-0.00049	2.10	2.9	1.00	2.30	0.70
11.0	209.6	107.5	-37.	-71.	0.	3.33	3.61	-1529.	-0.00053	2.40	3.0	1.10	2.30	0.90
11.0	210.4	109.0	-35.	-75.	0.	3.54	3.75	-1529.	-0.00055	2.60	3.0	1.10	2.40	0.80

Model Output 11-02-79 Actuals





11-12 FEBRUARY 1979



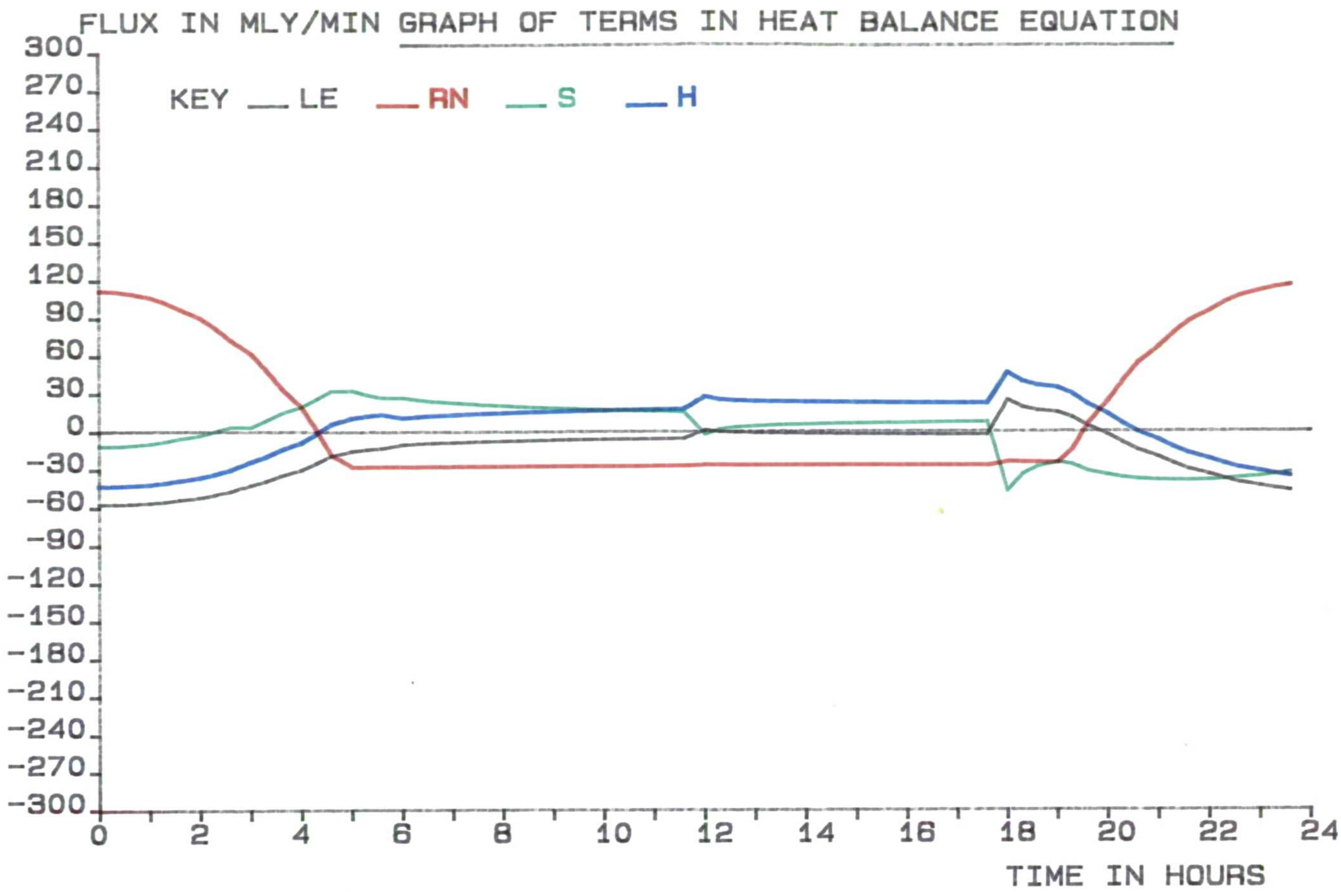
12-02-79

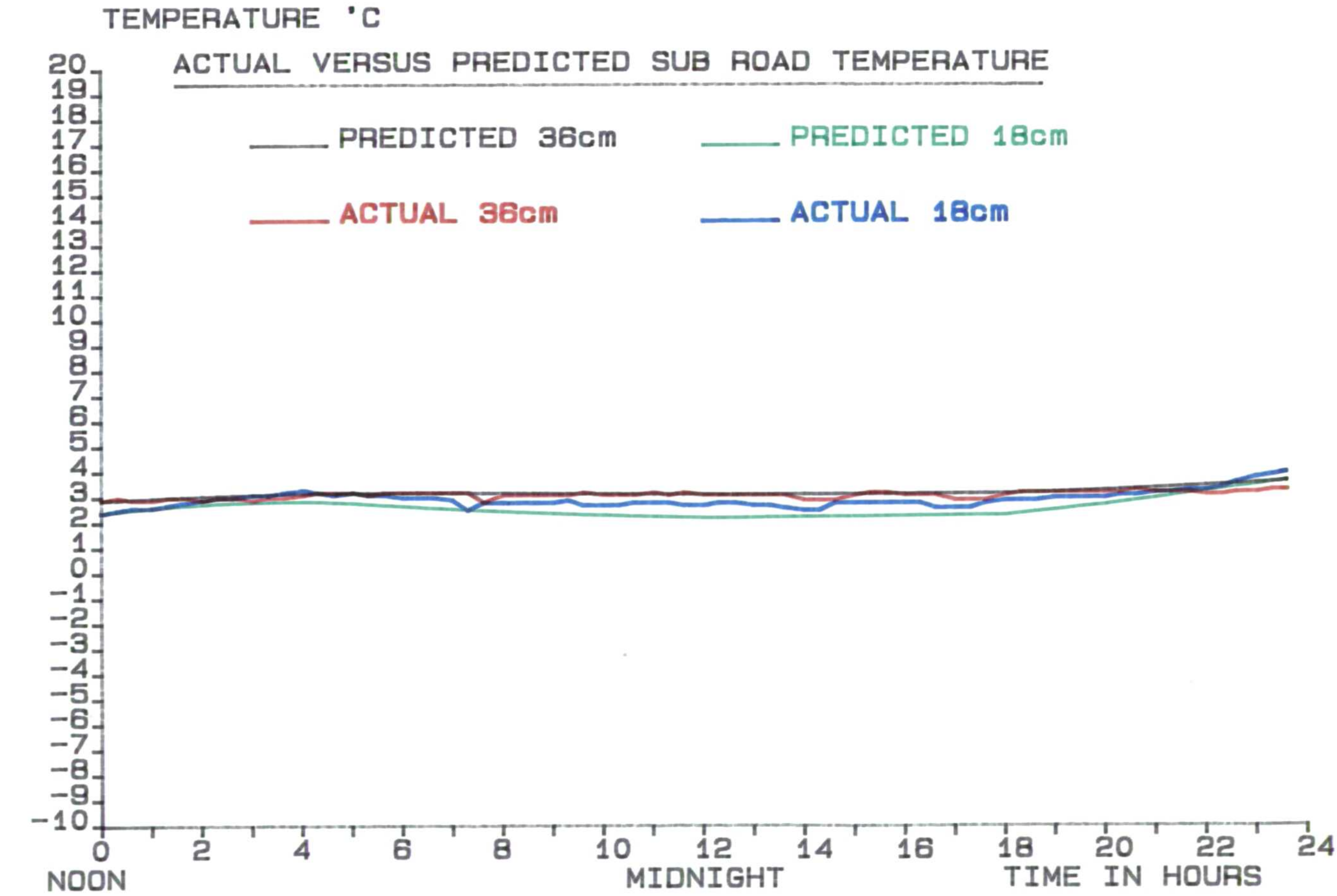
COMPUTED DATA
SAT. VAP. PRESSURE(MB)= 6.81
VAPOUR PRESSURE(MB)= 6.26
REL. HUMIDITY FRACTION = 0.92
APPROX. PRECIP. WATER(MM)= 10.0
ROAD DAMPING DEPTH(CM)= 72.
AIR DAMPING DEPTH(CM)= 2047. 2406.
AIR HEAT TRANSFER COEF.(CGS)= 0.00164 0.00220

DEC	R	T36	T18	TS	UA	D	TIME WET
-13.473	0.987	276.	1275.6	2.8	248. 354.	0.5	12

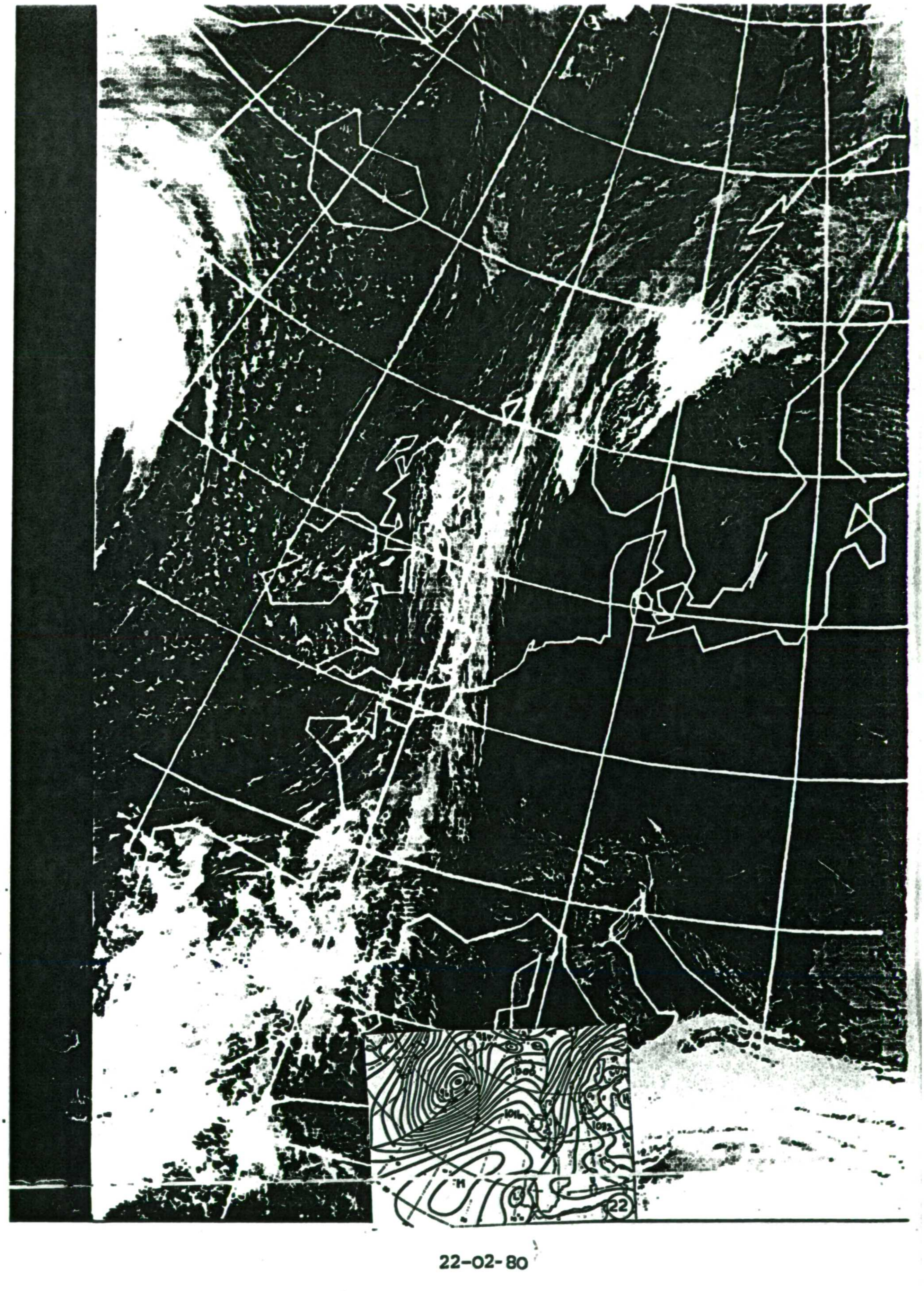
SOLAR TIME	SUN	RN	S	H	LE	TD	TC	SUM	RI	TO	T36	Air	T18	Tslab
			(ALL MLY./MIN.)				(C.)							
12.0	210.7	111.5	-12.	-43.	-57.	2.80	3.52	-56.	-0.00051	2.80	2.9	1.00	2.40	1.00
12.0	210.4	110.9	-12.	-43.	-57.	3.16	3.52	-57.	-0.00052	2.90	3.0	1.10	2.50	1.40
12.0	209.6	109.1	-11.	-42.	-57.	3.33	3.50	-114.	-0.00051	3.20	2.9	1.10	2.60	2.00
13.0	208.3	106.3	-9.	-42.	-56.	3.39	3.46	-170.	-0.00050	3.60	2.9	1.50	2.60	2.90
13.0	206.3	102.1	-8.	-40.	-55.	3.40	3.41	-225.	-0.00048	4.20	3.0	1.50	2.70	2.60
13.0	203.7	96.7	-5.	-39.	-53.	3.37	3.33	-278.	-0.00046	4.30	3.0	1.80	2.60	4.10
14.0	200.5	90.0	-3.	-36.	-52.	3.30	3.24	-330.	-0.00044	4.10	2.9	1.80	2.90	3.80
14.0	196.4	81.9	0.	-34.	-49.	3.21	3.12	-379.	-0.00040	4.10	3.0	1.60	3.00	3.20
14.0	191.4	72.3	4.	-30.	-47.	3.10	2.98	-425.	-0.00036	3.70	3.0	1.80	3.00	3.10
15.0	185.1	61.6	4.	-24.	-42.	3.01	2.91	-468.	-0.00029	3.40	2.9	1.60	3.10	2.90
15.0	177.2	46.9	9.	-20.	-39.	2.87	2.74	-506.	-0.00024	3.40	3.0	1.80	3.10	2.80
15.0	166.6	34.7	15.	-14.	-34.	2.69	2.51	-541.	-0.00017	3.30	3.0	1.90	3.20	2.70
16.0	151.5	18.9	20.	-8.	-30.	2.47	2.26	-570.	-0.00010	3.20	3.1	1.60	3.30	2.80
16.0	126.0	1.2	26.	-2.	-25.	2.22	1.97	-595.	-0.00002	3.00	3.2	1.90	3.20	2.50
16.0	65.5	-18.7	32.	6.	-19.	1.93	1.64	-614.	0.00007	2.90	3.2	2.00	3.10	2.30
17.0	0.0	-28.2	32.	11.	-15.	1.69	1.44	-629.	0.00013	2.70	3.2	1.50	3.20	2.10
17.0	0.0	-28.0	29.	13.	-14.	1.53	1.36	-643.	0.00015	2.60	3.1	1.50	3.10	2.10
17.0	0.0	-27.9	27.	14.	-13.	1.42	1.31	-656.	0.00017	2.50	3.2	1.30	3.10	1.60
18.0	0.0	-28.0	27.	11.	-10.	1.33	1.23	-666.	0.00013	2.50	3.2	1.40	3.00	1.60
18.0	0.0	-27.9	25.	12.	-9.	1.26	1.19	-675.	0.00015	2.40	3.2	1.40	3.00	1.70
18.0	0.0	-27.9	24.	13.	-9.	1.21	1.16	-684.	0.00015	2.40	3.2	1.50	3.00	1.60
19.0	0.0	-27.8	23.	13.	-8.	1.17	1.14	-692.	0.00016	2.40	3.2	1.50	2.90	1.70
19.0	0.0	-27.8	22.	14.	-8.	1.14	1.11	-700.	0.00017	2.50	3.2	1.60	2.50	1.70
19.0	0.0	-27.7	21.	14.	-8.	1.12	1.09	-708.	0.00017	2.00	2.8	1.20	2.80	1.30
20.0	0.0	-27.7	20.	15.	-7.	1.10	1.08	-715.	0.00018	2.40	3.1	1.50	2.80	1.70
20.0	0.0	-27.6	19.	15.	-7.	1.08	1.06	-722.	0.00018	2.30	3.1	1.30	2.80	1.40
20.0	0.0	-27.6	19.	16.	-7.	1.06	1.04	-729.	0.00019	2.30	3.1	1.40	2.80	1.60
21.0	0.0	-27.6	18.	16.	-7.	1.05	1.03	-735.	0.00019	2.30	3.1	1.50	2.80	1.60
21.0	0.0	-27.6	18.	16.	-6.	1.03	1.02	-741.	0.00020	2.40	3.1	1.60	2.90	1.70
21.0	0.0	-27.5	17.	16.	-6.	1.02	1.01	-748.	0.00020	2.40	3.2	1.60	2.70	1.70
22.0	0.0	-27.5	17.	17.	-6.	1.01	1.00	-753.	0.00020	2.30	3.1	1.60	2.70	1.70
22.0	0.0	-27.5	16.	17.	-6.	1.00	0.99	-759.	0.00020	2.20	3.1	1.40	2.70	1.50
22.0	0.0	-27.5	16.	17.	-6.	0.99	0.98	-765.	0.00021	2.30	3.1	1.40	2.80	1.50
23.0	0.0	-27.5	16.	17.	-6.	0.98	0.97	-771.	0.00021	2.40	3.2	1.60	2.80	1.60
23.0	0.0	-27.5	15.	17.	-5.	0.97	0.97	-776.	0.00021	2.30	3.1	1.50	2.80	1.60
23.0	0.0	-27.4	15.	18.	-5.	0.97	0.96	-781.	0.00021	2.40	3.2	1.60	2.70	1.70
0.0	0.0	-26.7	-2.	28.	1.	1.17	1.37	-780.	0.00013	2.30	3.1	1.70	2.70	1.60
0.0	0.0	-26.9	2.	25.	0.	1.30	1.44	-780.	0.00012	2.30	3.1	1.70	2.80	1.60
0.0	0.0	-26.9	3.	25.	-1.	1.38	1.46	-781.	0.00011	2.30	3.1	1.80	2.80	1.50
1.0	0.0	-27.0	4.	24.	-1.	1.43	1.48	-782.	0.00011	2.30	3.1	1.80	2.70	1.50
1.0	0.0	-27.0	5.	24.	-1.	1.46	1.49	-783.	0.00011	2.30	3.1	1.80	2.70	1.50
1.0	0.0	-27.0	5.	23.	-2.	1.48	1.50	-785.	0.00011	2.30	3.1	1.90	2.60	1.50
2.0	0.0	-27.0	5.	23.	-2.	1.49	1.50	-787.	0.00011	2.10	2.9	1.70	2.50	1.40
2.0	0.0	-27.0	6.	23.	-2.	1.50	1.51	-788.	0.00011	2.10	2.9	1.70	2.50	1.40
2.0	0.0	-27.0	6.	23.	-2.	1.51	1.51	-790.	0.00010	2.20	2.9	1.90	2.80	1.50
3.0	0.0	-27.0	6.	23.	-2.	1.51	1.52	-792.	0.00010	2.40	3.1	2.20	2.80	1.70
3.0	0.0	-27.0	6.	23.	-2.	1.52	1.52	-795.	0.00010	2.60	3.2	2.30	2.80	1.80
3.0	0.0	-27.1	7.	23.	-2.	1.52	1.52	-797.	0.00010	2.60	3.2	2.40	2.80	1.90
4.0	0.0	-27.1	7.	23.	-2.	1.52	1.53	-799.	0.00010	2.60	3.1	2.40	2.80	2.00
4.0	0.0	-27.1	7.	22.	-2.	1.53	1.53	-801.	0.00010	2.60	3.1	2.40	2.60	1.80
4.0	0.0	-27.1	7.	22.	-2.	1.53	1.53	-804.	0.00010	2.60	3.1	2.40	2.60	1.90
5.0	0.0	-27.1	7.	22.	-2.	1.53	1.53	-806.	0.00010	2.40	2.9	2.20	2.60	1.70
5.0	0.0	-27.1	7.	22.	-2.	1.53	1.54	-809.	0.00010	2.50	2.9	2.30	2.60	1.80
5.0	0.0	-27.1	7.	22.	-2.	1.54	1.54	-811.	0.00010	2.50	2.9	2.20	2.80	1.80
6.0	0.0	-24.2	-47.	47.	25.	2.20	2.86	-786.	0.00021	2.80	3.1	2.50	2.90	2.00
6.0	0.0	-24.7	-34.	40.	19.	2.64	3.09	-767.	0.00018	2.90	3.2	2.50	2.90	2.20
6.0	0.0	-24.9	-28.	36.	16.	2.92	3.19	-751.	0.00017	3.00	3.2	2.60	2.90	2.10
7.0	0.0	-25.0	-24.	35.	15.	3.08	3.25	-736.	0.00016	3.00	3.2	2.70	3.00	2.20
7.0	71.3	-14.1	-26.	30.	11.	3.24	3.40	-725.	0.00013	3.10	3.2	2.80	3.00	2.40
7.0	128.1	5.9	-32.	22.	4.	3.45	3.66	-721.	0.00010	3.20	3.2	3.00	3.00	2.30
8.0	152.8	23.6	-35.	14.	-3.	3.68	3.91	-723.	0.00006	3.40	3.2	3.20	3.00	2.40
8.0	167.5	39.4	-37.	6.	-9.	3.91	4.14	-732.	0.00003	3.70	3.2	3.40	3.10	2.70
8.0	177.9	53.6	-38.	0.	-15.	4.13	4.36	-747.	0.00000	3.80	3.3	3.50	3.10	2.90
9.0	185.8	66.3	-39.	-7.	-20.	4.34	4.55	-767.	-0.00003	4.00	3.2	3.80	3.20	3.10
9.0	192.0	77.3	-39.	-12.	-26.	4.54	4.73	-793.	-0.00006	4.30	3.2	4.20	3.20	3.60
9.0	196.9	86.8	-39.	-17.	-30.	4.71	4.89	-823.	-0.00008	4.70	3.2	4.60	3.30	4.00
10.0	201.0	94.8	-39.	-22.	-34.	4.87	[illegible]	-857.	[illegible]	5.00	3.1	4.80	3.30	4.60
10.0	204.3	101.5	-38.	-26.	-38.	5.01	5.15	-895.	-0.00012	5.40	3.1	5.10	3.40	4.90
10.0	206.8	106.8	-37.	-29.	-41.	5.13	5.26	-936.	-0.00013	5.60	3.2	5.50	3.60	5.00
11.0	208.8	110.9	-36.	-32.	-43.	5.24	5.34	-979.	-0.00014	6.10	3.2	5.90	3.80	5.60
11.0	210.1	113.8	-34.	-34.	-45.	5.33	5.41	-1024.	-0.00015	6.40	3.3	6.30	3.90	5.80
11.0	210.9	115.4	-33.	-36.	-47.	5.40	5.47	-1072.	-0.00016	6.70	3.3	6.60	4.00	6.20

Model Output 12-02-79 Actuals





12-13 FEBRUARY 1979



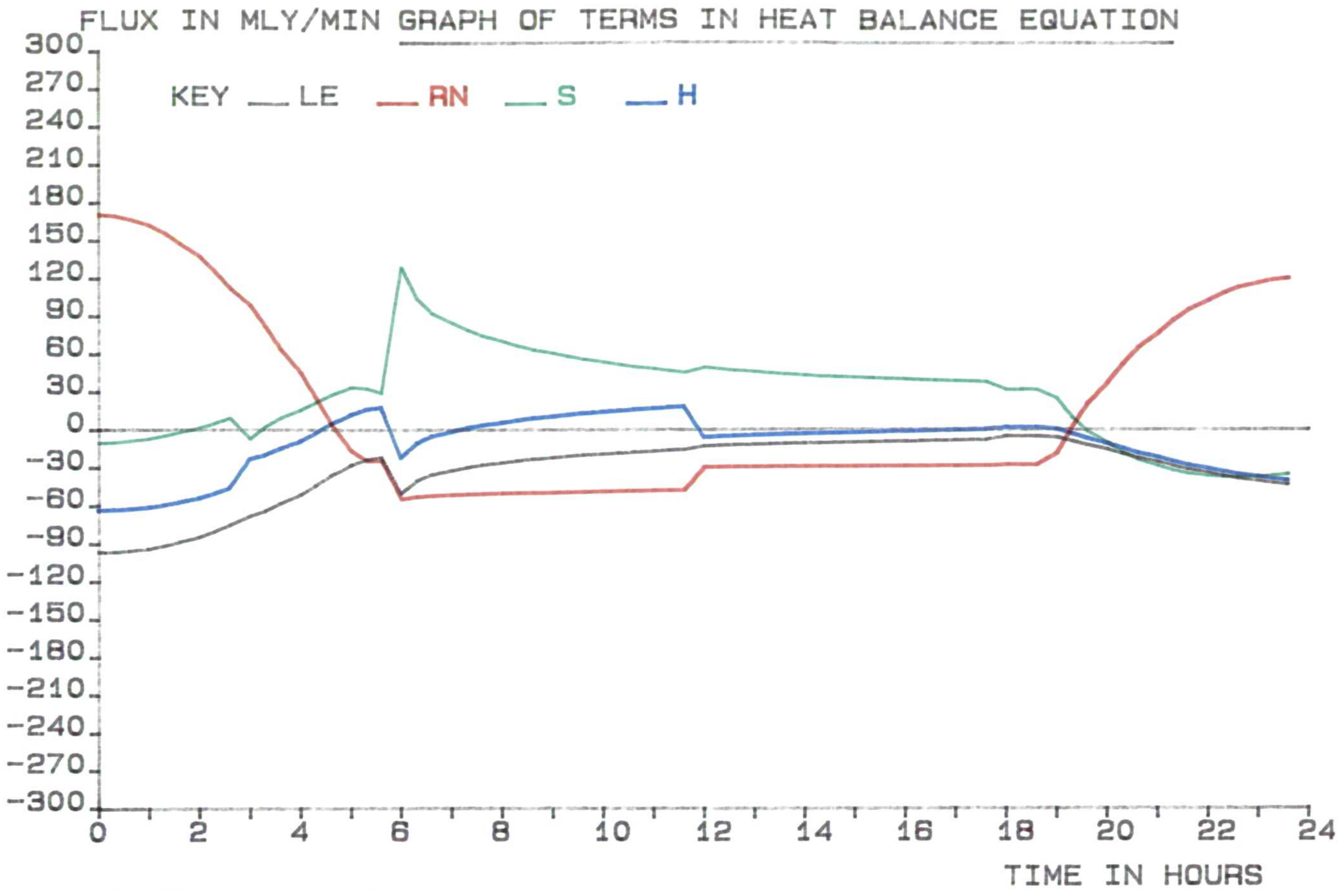
22-02-80

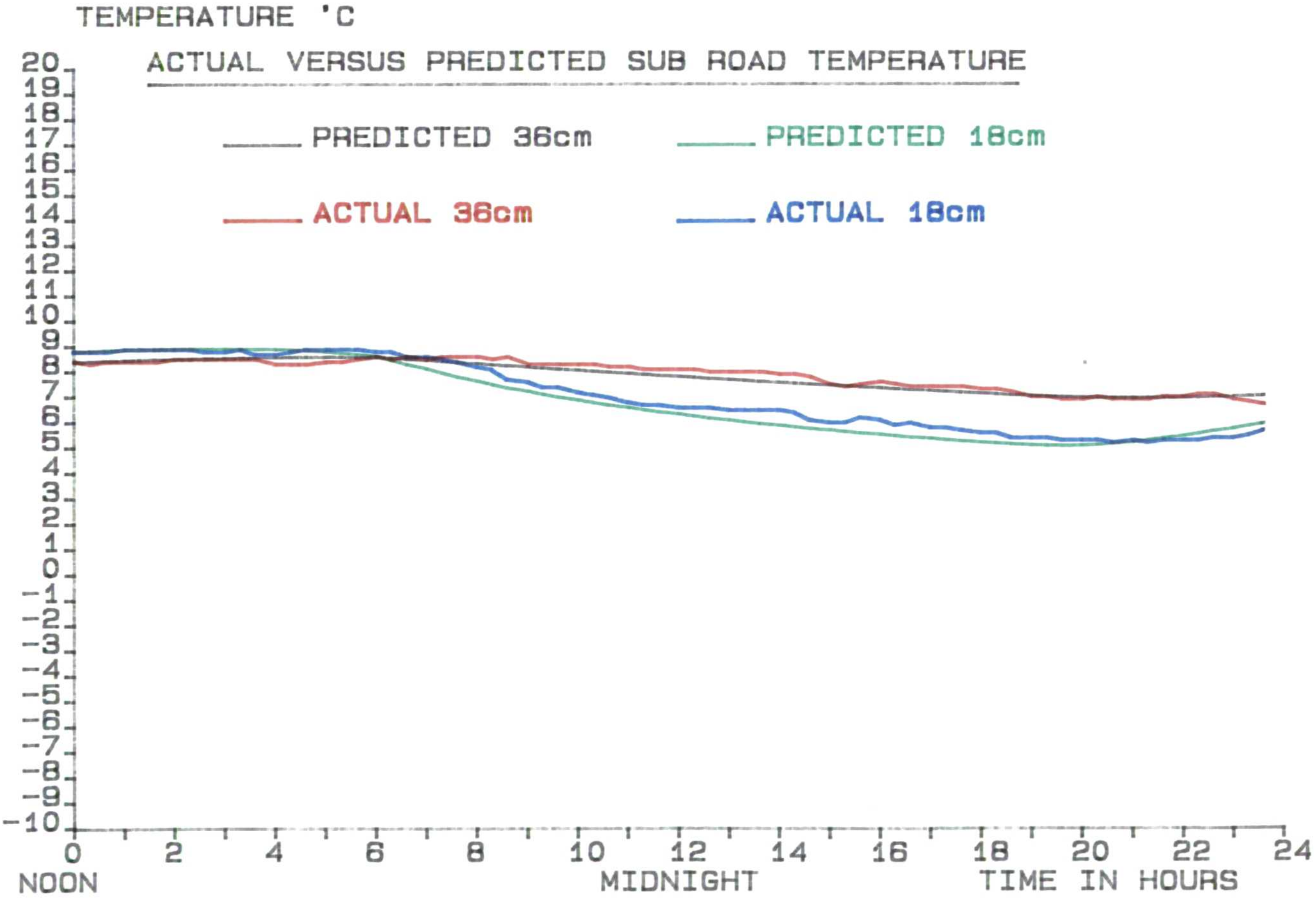
COMPUTED DATA
SAT. VAP. PRESSURE(MB)= 9.88
VAPOUR PRESSURE(MB)= 9.28
REL. HUMIDITY FRACTION = 0.94
APPROX. PRECIP. WATER(MM)= 14.5
ROAD DAMPING DEPTH(CM)= 72.
AIR DAMPING DEPTH(CM)= 1986. 1157.
AIR HEAT TRANSFER COEF.(CGS)= 0.00156 0.00059

DEC	R	T36	T18	TS	UA	D	TIME WET
-10.045	0.989	281.6	282.0	8.5	232. 70.	0.5	12

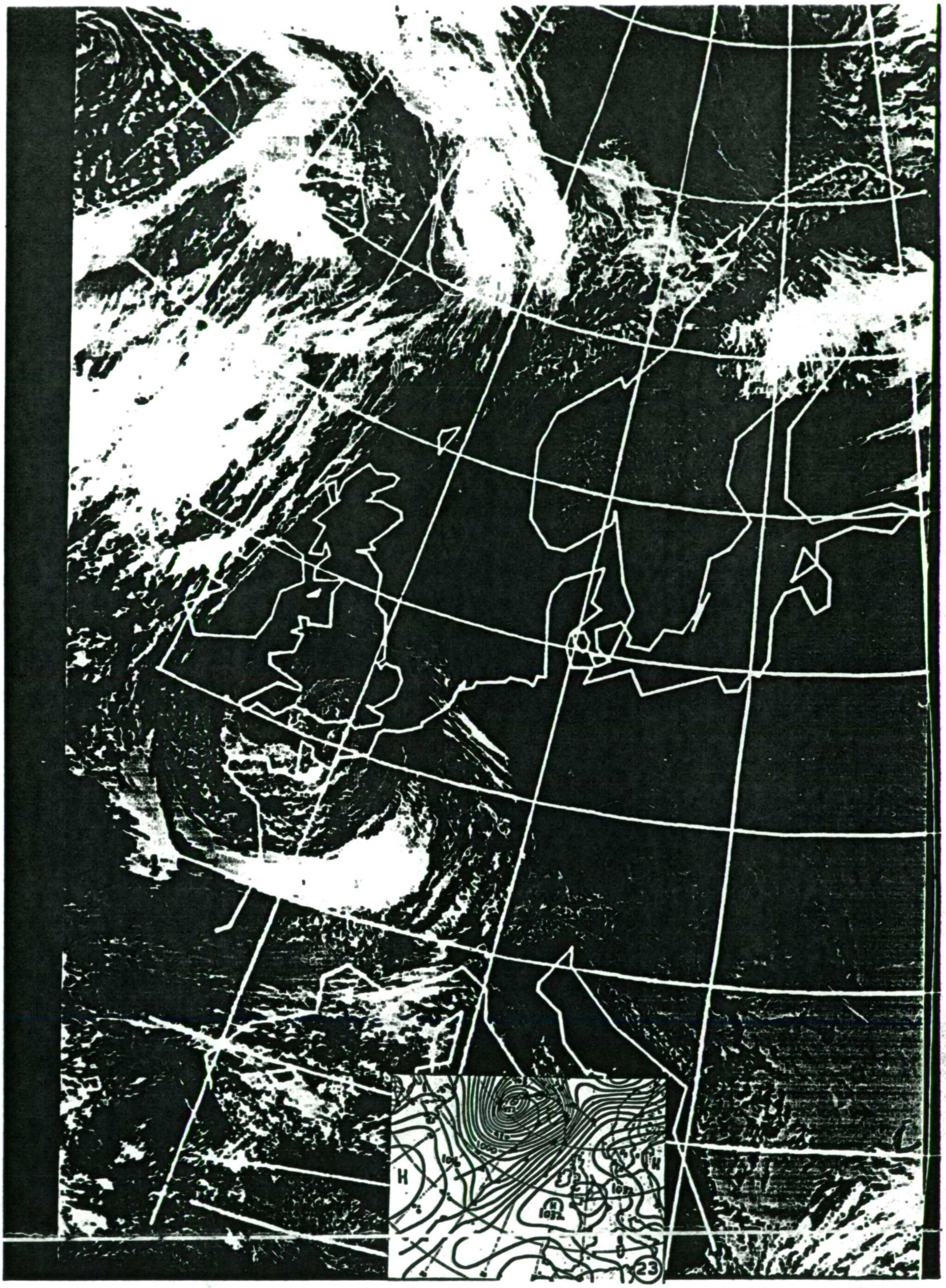
SOLAR TIME	SUN	RN	S (ALL MLY./MIN.)	H	LE	TD	TC (C.)	SUM	RI	TO	T36	Air	T18	Tslab
12.0	278.9	170.1	-10.	-63.	-96.	8.50	9.81	-95.	-0.00089	8.50	8.40	6.50	8.80	8.20
12.0	278.3	169.1	-10.	-63.	-96.	9.15	9.80	-96.	-0.00089	8.50	8.30	6.00	8.80	8.30
12.0	276.4	166.4	-9.	-62.	-95.	9.46	9.77	-191.	-0.00088	8.50	8.40	6.50	8.80	8.30
13.0	273.2	161.8	-7.	-61.	-94.	9.59	9.72	-285.	-0.00086	8.50	8.40	6.60	8.90	8.40
13.0	268.7	155.4	-5.	-59.	-91.	9.61	9.63	-376.	-0.00083	9.00	8.40	6.80	8.90	8.40
13.0	263.0	147.1	-2.	-57.	-88.	9.57	9.53	-464.	-0.00080	9.00	8.40	6.80	8.90	8.50
14.0	256.0	137.1	1.	-54.	-85.	9.48	9.39	-549.	-0.00076	9.00	8.50	7.00	8.90	8.70
14.0	247.6	125.3	5.	-50.	-80.	9.35	9.23	-629.	-0.00071	9.00	8.50	7.20	8.90	8.70
14.0	237.9	111.8	9.	-46.	-75.	9.20	9.04	-704.	-0.00065	9.30	8.50	7.50	8.80	9.00
15.0	226.6	98.3	-7.	-23.	-68.	9.26	9.32	-773.	-0.00032	9.20	8.50	7.80	8.80	9.20
15.0	213.9	81.5	2.	-20.	-64.	9.22	9.18	-837.	-0.00028	10.30	8.50	9.10	8.90	11.30
15.0	199.2	63.6	9.	-15.	-58.	9.09	8.95	-895.	-0.00021	10.30	8.50	9.00	8.70	11.20
16.0	181.8	44.7	16.	-9.	-51.	8.89	8.69	-946.	-0.00012	10.20	8.30	9.30	8.70	10.80
16.0	159.8	24.9	22.	-2.	-44.	8.65	8.40	-990.	-0.00003	9.70	8.30	9.00	8.80	9.00
16.0	127.5	4.4	27.	5.	-36.	8.37	8.09	-1027.	0.00007	9.20	8.30	7.50	8.90	8.90
17.0	57.7	-17.1	33.	12.	-28.	8.06	7.76	-1055.	0.00017	8.90	8.40	7.20	8.90	8.40
17.0	0.0	-25.0	32.	16.	-24.	7.82	7.57	-1078.	0.00023	8.30	8.40	7.00	8.90	7.60
17.0	0.0	-24.8	29.	18.	-22.	7.66	7.50	-1100.	0.00025	8.10	8.50	6.60	8.90	7.20
18.0	0.0	-55.2	128.	-22.	-51.	6.32	4.98	-1151.	-0.00032	8.00	8.60	6.50	8.80	7.00
18.0	0.0	-53.3	103.	-11.	-40.	5.40	4.48	-1191.	-0.00015	7.70	8.50	6.30	8.80	6.80
18.0	0.0	-52.3	92.	-5.	-35.	4.81	4.22	-1226.	-0.00007	7.10	8.60	5.80	8.60	6.00
19.0	0.0	-51.7	84.	-1.	-32.	4.43	4.06	-1258.	-0.00002	6.60	8.50	5.20	8.60	5.40
19.0	0.0	-51.2	78.	1.	-30.	4.18	3.93	-1288.	0.00002	6.30	8.60	5.00	8.50	4.90
19.0	0.0	-50.8	74.	4.	-28.	4.01	3.83	-1316.	0.00005	6.00	8.60	4.80	8.40	4.60
20.0	0.0	-50.5	70.	6.	-26.	3.87	3.74	-1342.	0.00008	5.60	8.60	3.90	8.20	4.20
20.0	0.0	-50.2	66.	8.	-24.	3.77	3.66	-1366.	0.00011	5.40	8.50	4.10	8.10	4.00
20.0	0.0	-49.9	63.	9.	-23.	3.68	3.59	-1389.	0.00013	5.10	8.60	4.50	7.70	3.70
21.0	0.0	-49.6	60.	11.	-22.	3.60	3.53	-1411.	0.00015	4.60	8.30	3.50	7.60	3.20
										4.40	8.30	2.90	7.40	3.00
21.0	0.0	-49.4	57.	12.	-21.	3.54	3.47	-1432.	0.00017	4.00	8.30	2.60	7.40	2.70
21.0	0.0	-49.2	55.	13.	-20.	3.48	3.42	-1452.	0.00019	4.10	8.30	3.10	7.20	2.70
22.0	0.0	-49.0	53.	14.	-19.	3.42	3.37	-1471.	0.00020	4.10	8.30	3.10	7.10	2.50
22.0	0.0	-48.9	51.	15.	-18.	3.37	3.33	-1489.	0.00022	3.70	8.20	1.10	7.00	2.20
22.0	0.0	-48.7	49.	16.	-17.	3.33	3.29	-1506.	0.00023	3.80	8.20	1.80	6.80	2.40
23.0	0.0	-48.6	48.	17.	-17.	3.29	3.25	-1523.	0.00024	3.90	8.10	1.70	6.70	2.70
23.0	0.0	-48.5	46.	18.	-16.	3.25	3.21	-1539.	0.00025	4.00	8.10	2.20	6.70	2.80
23.0	0.0	-48.3	45.	18.	-16.	3.22	3.18	-1555.	0.00026	4.30	8.10	2.60	6.60	3.10
0.0	0.0	-30.2	49.	-6.	-13.	3.12	3.02	-1568.	-0.00222	4.40	8.10	2.70	6.60	3.30
0.0	0.0	-30.0	47.	-5.	-13.	3.03	2.94	-1580.	-0.00198	4.30	8.00	2.70	6.60	3.20
0.0	0.0	-29.9	46.	-5.	-12.	2.96	2.88	-1592.	-0.00179	4.50	8.00	3.00	6.50	3.50
1.0	0.0	-29.8	45.	-4.	-12.	2.89	2.83	-1604.	-0.00162	4.60	8.00	2.90	6.50	3.60
1.0	0.0	-29.7	45.	-4.	-11.	2.84	2.78	-1615.	-0.00146	4.70	8.00	2.90	6.50	3.70
1.0	0.0	-29.6	44.	-4.	-11.	2.79	2.73	-1626.	-0.00132	4.70	7.90	3.00	6.50	3.70
2.0	0.0	-29.5	43.	-3.	-11.	2.74	2.69	-1637.	-0.00118	4.60	7.90	3.20	6.40	3.70
2.0	0.0	-29.4	42.	-3.	-10.	2.70	2.65	-1647.	-0.00107	4.40	7.80	2.80	6.10	3.30
2.0	0.0	-29.3	42.	-3.	-10.	2.65	2.61	-1658.	-0.00094	3.70	7.50	2.20	6.00	2.60
3.0	0.0	-29.2	41.	-2.	-10.	2.61	2.57	-1668.	-0.00081	3.50	7.40	2.10	6.00	2.30
3.0	0.0	-29.2	40.	-2.	-10.	2.57	2.53	-1677.	-0.00069	3.30	7.50	1.50	6.20	2.00
3.0	0.0	-29.1	40.	-2.	-9.	2.53	2.49	-1687.	-0.00056	3.20	7.60	1.30	6.10	2.00
4.0	0.0	-29.0	39.	-1.	-9.	2.50	2.46	-1696.	-0.00045	3.00	7.50	1.60	5.90	1.60
4.0	0.0	-28.9	39.	-1.	-9.	2.46	2.42	-1705.	-0.00033	2.90	7.40	1.40	6.00	1.70
4.0	0.0	-28.9	39.	-1.	-9.	2.42	2.39	-1713.	-0.00022	2.90	7.40	0.90	5.80	1.60
5.0	0.0	-28.8	38.	0.	-8.	2.39	2.35	-1722.	-0.00012	3.00	7.40	0.90	5.80	1.60
5.0	0.0	-28.7	38.	0.	-8.	2.35	2.32	-1730.	-0.00001	3.10	7.40	1.20	5.70	1.60
5.0	0.0	-28.7	37.	0.	-8.	2.32	2.29	-1738.	0.00009	3.00	7.30	1.20	5.60	1.80
6.0	0.0	-27.8	31.	2.	-5.	2.36	2.40	-1743.	0.00069	3.10	7.30	1.10	5.60	1.90
6.0	0.0	-27.9	31.	2.	-5.	2.39	2.41	-1748.	0.00065	3.30	7.20	1.10	5.40	2.00
6.0	0.0	-27.9	31.	2.	-5.	2.40	2.41	-1753.	0.00065	3.40	7.00	1.40	5.40	1.90
7.0	64.1	-18.6	25.	0.	-6.	2.48	2.56	-1759.	0.00017	3.50	7.00	1.50	5.40	2.00
7.0	126.7	2.0	10.	-3.	-9.	2.73	2.98	-1768.	-0.00114					
7.0	152.6	20.2	-2.	-7.	-12.	3.08	3.42	-1780.	-0.00254	3.60	6.90	1.60	5.30	2.40
8.0	168.0	36.6	-11.	-11.	-16.	3.47	3.87	-1795.	-0.00395	3.70	6.90	2.20	5.30	2.70
8.0	178.8	51.3	-18.	-15.	-19.	3.89	4.30	-1814.	-0.00531	3.80	7.00	2.40	5.30	2.90
8.0	186.9	64.4	-24.	-18.	-22.	4.30	4.72	-1837.	-0.00660	3.90	6.90	2.00	5.20	2.90
9.0	193.5	76.0	-29.	-22.	-25.	4.70	5.11	-1862.	-0.00781	4.30	6.90	2.10	5.30	3.10
9.0	198.8	85.9	-33.	-25.	-29.	5.08	5.46	-1891.	-0.00893	4.80	6.90	2.40	5.20	3.40
9.0	203.2	94.5	-35.	-28.	-31.	5.44	5.79	-1922.	-0.00995	5.30	7.00	2.20	5.30	3.50
10.0	206.8	101.7	-37.	-31.	-34.	5.76	6.09	-1956.	-0.01087	5.40	7.00	2.70	[illegible]	[illegible]
10.0	209.8	107.6	-38.	-33.	-37.	6.06	6.35	-1993.	-0.01170	5.40	7.10	3.10	5.30	4.90
10.0	212.1	112.3	-38.	-36.	-39.	6.32	6.59	-2031.	-0.01243	5.50	7.10	3.30	5.40	5.30
11.0	213.9	115.9	-38.	-38.	-41.	6.56	6.79	-2072.	-0.01306	5.50	6.90	4.00	5.40	5.90
11.0	215.1	118.3	-37.	-39.	-42.	6.76	6.96	-2115.	-0.01360	6.40	6.80	5.00	5.50	7.10
11.0	215.9	119.6	-36.	-41.	-44.	6.93	7.11	-2158.	-0.01405	6.50	6.70	5.40	5.70	7.20

Model Ouput 22-02-80 Actuals





22-23 FEBRUARY 1980



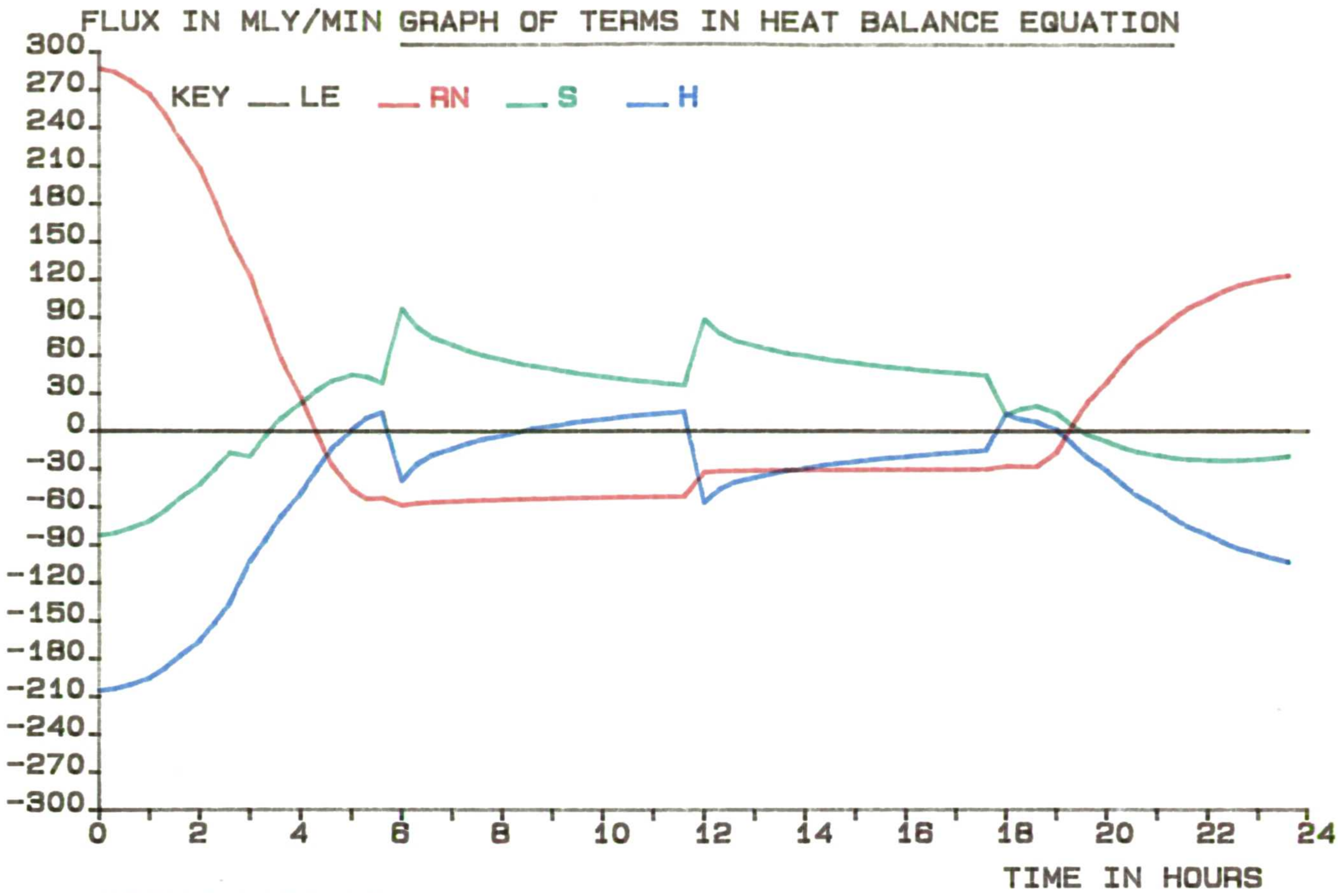
23-02-80

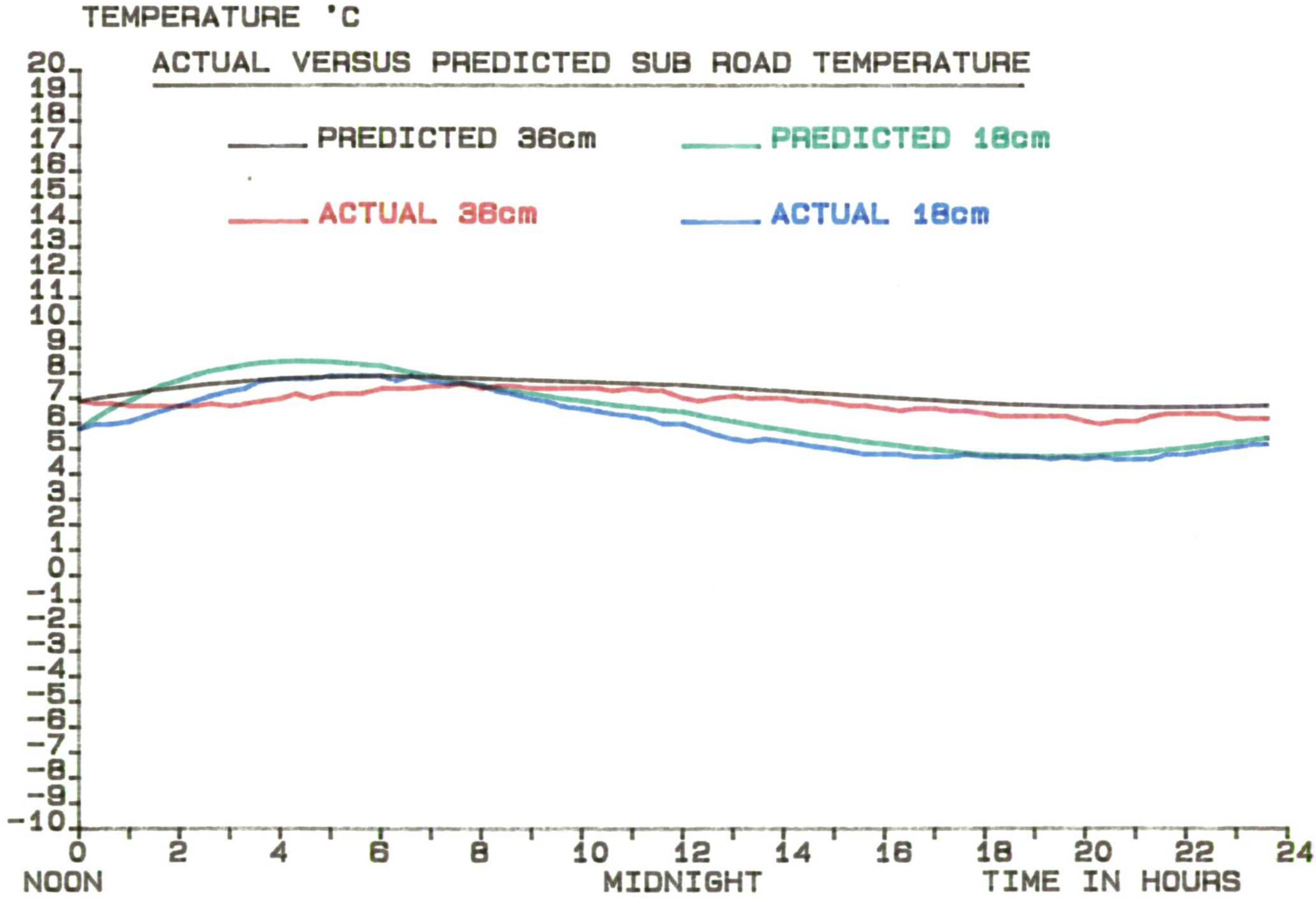
COMPUTED DATA
SAT. VAP. PRESSURE(MB)= 9.88
VAPOUR PRESSURE(MB)= 8.20
REL. HUMIDITY FRACTION = 0.83
APPROX. PRECIP. WATER(MM)= 12.9
ROAD DAMPING DEPTH(CM)= 72.
AIR DAMPING DEPTH(CM)= 2349. 2424.
AIR HEAT TRANSFER COEF.(CGS)= 0.00210 0.00223

DEC	R	T36	T18	TS	UA	D	TIME WET
-9.678	0.990	280.1	279.0	7.4	336. 360.	0.5	0

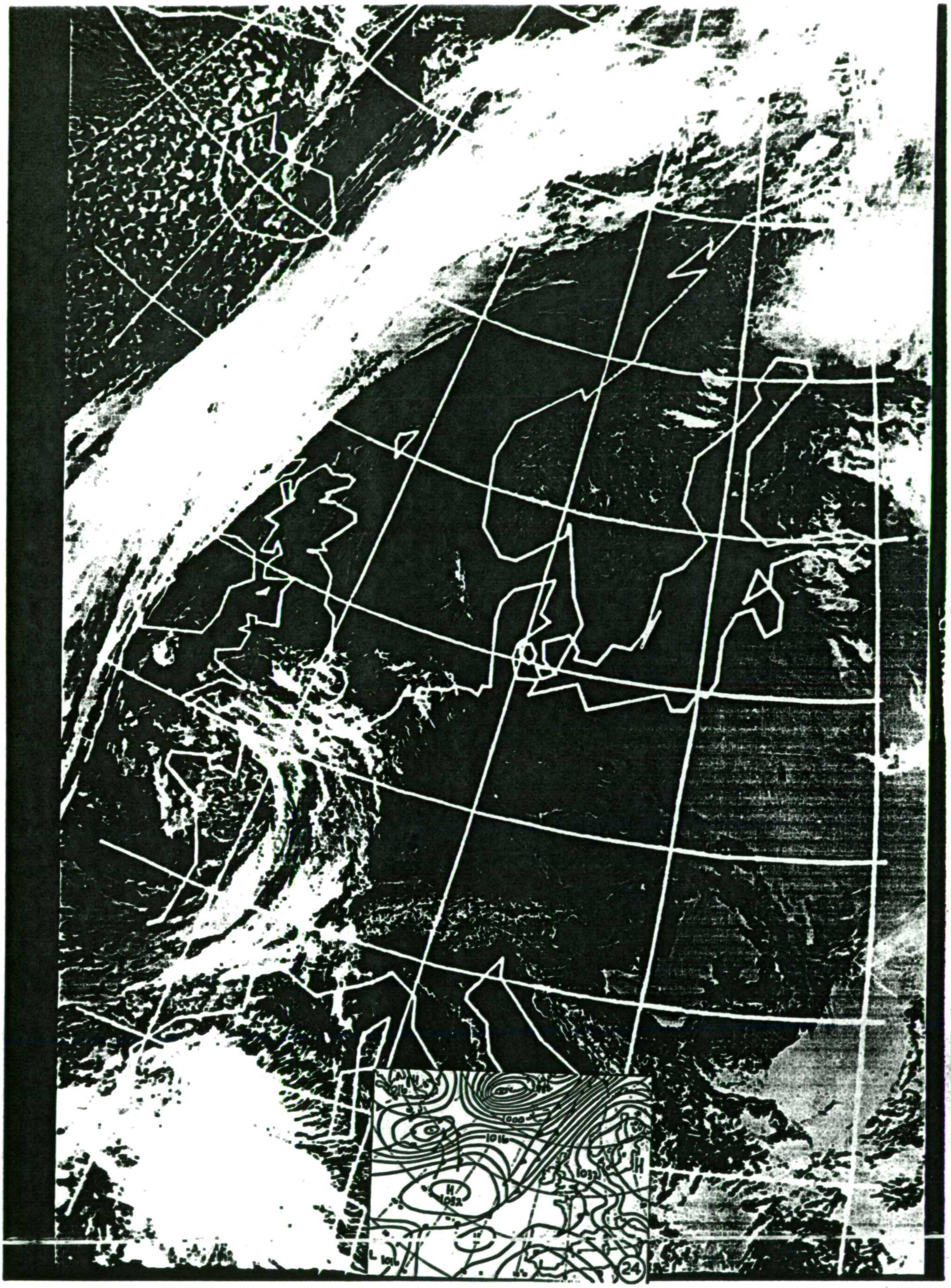
SOLAR TIME	SUN	RN	S	H	LE	TD	TC (C.)	SUM	RI	TO	T36	Air	T18	Tslab
		(ALL MLY./MIN.)												
12.0	498.9	286.4	-82.	-205.	0.	7.40	13.76	1.	-0.00104	7.40	6.9	5.70	5.80	8.00
12.0	496.7	284.1	-81.	-204.	0.	10.56	13.73	0.	-0.00104	6.80	6.8	5.70	6.00	7.00
12.0	490.2	277.2	-77.	-201.	0.	12.09	13.62	0.	-0.00102	7.80	6.8	6.40	6.00	8.80
13.0	479.5	266.1	-71.	-195.	0.	12.77	13.45	0.	-0.00099	9.60	6.7	6.50	6.10	10.50
13.0	464.4	250.5	-63.	-188.	0.	12.99	13.20	0.	-0.00096	10.10	6.7	7.30	6.30	10.90
13.0	445.2	230.8	-53.	-178.	0.	12.94	12.88	0.	-0.00091	10.30	6.7	7.60	6.50	11.20
14.0	422.4	207.8	-42.	-166.	0.	12.71	12.49	0.	-0.00085	9.80	6.7	7.30	6.70	10.30
14.0	395.6	181.4	-30.	-152.	0.	12.37	12.03	0.	-0.00076	10.10	6.7	7.10	6.90	9.80
14.0	365.4	152.4	-17.	-136.	0.	11.94	11.50	0.	-0.00069	9.40	6.8	7.30	7.10	9.30
15.0	335.8	122.0	-20.	-103.	0.	11.62	11.31	0.	-0.00052	10.20	6.7	7.90	7.30	10.10
15.0	299.0	89.6	-4.	-86.	0.	11.20	10.78	0.	-0.00044	10.30	6.8	7.80	7.40	9.90
15.0	259.4	57.4	10.	-68.	0.	10.69	10.17	0.	-0.00035	9.90	6.9	8.00	7.70	9.50
16.0	217.2	26.6	22.	-49.	0.	10.12	9.56	0.	-0.00025	10.30	7.0	8.30	7.80	10.00
16.0	171.9	-1.8	32.	-31.	0.	9.54	8.96	0.	-0.00016	9.50	7.2	7.40	7.80	8.50
16.0	121.8	-26.3	39.	-14.	0.	8.97	8.40	0.	-0.00007	9.30	7.0	8.20	7.80	8.40
17.0	55.6	-46.1	44.	1.	0.	8.44	7.91	0.	0.00000	9.10	7.2	7.70	7.90	8.00
17.0	0.0	-53.4	43.	10.	0.	8.02	7.59	0.	0.00005	8.70	7.2	7.20	7.90	7.40
17.0	0.0	-52.8	38.	15.	0.	7.73	7.44	0.	0.00008	8.20	7.2	6.90	7.90	7.00
18.0	0.0	-58.6	97.	-39.	0.	6.77	5.82	0.	-0.00020	7.60	7.4	6.20	7.90	6.20
18.0	0.0	-56.9	82.	-26.	0.	6.08	5.39	0.	-0.00014	7.10	7.4	6.20	7.70	5.70
18.0	0.0	-56.0	74.	-19.	0.	5.62	5.15	0.	-0.00010	6.90	7.4	6.20	7.90	5.50
19.0	0.0	-55.3	68.	-14.	0.	5.30	4.98	0.	-0.00007	6.50	7.5	5.70	7.70	5.00
19.0	0.0	-54.8	63.	-10.	0.	5.08	4.85	0.	-0.00005	6.10	7.5	5.60	7.60	4.70
19.0	0.0	-54.4	60.	-6.	0.	4.91	4.74	0.	-0.00003	5.60	7.6	5.00	7.60	4.10
20.0	0.0	-54.0	56.	-3.	0.	4.78	4.64	0.	-0.00002	5.50	7.4	5.00	7.50	3.90
20.0	0.0	-53.7	53.	-1.	0.	4.67	4.56	0.	0.00000	5.20	7.5	4.50	7.30	3.60
20.0	0.0	-53.3	51.	2.	0.	4.57	4.47	0.	0.00001	4.90	7.5	4.40	7.20	3.30
21.0	0.0	-53.1	49.	4.	0.	4.48	4.40	0.	0.00002	4.60	7.4	4.20	7.00	2.90
										4.40	7.4	3.20	6.90	2.60
21.0	0.0	-52.8	47.	6.	0.	4.41	4.33	0.	0.00003	4.20	7.4	3.30	6.70	2.20
21.0	0.0	-52.6	45.	8.	0.	4.34	4.27	0.	0.00004	3.90	7.4	3.40	6.60	2.10
22.0	0.0	-52.4	43.	9.	0.	4.28	4.22	0.	0.00005	3.70	7.4	3.00	6.50	1.80
22.0	0.0	-52.2	41.	11.	0.	4.23	4.17	0.	0.00006	3.50	7.3	3.30	6.40	1.70
22.0	0.0	-52.0	40.	12.	0.	4.18	4.13	0.	0.00006	3.40	7.3	2.30	6.30	1.60
23.0	0.0	-51.9	38.	13.	0.	4.13	4.09	0.	0.00007	3.20	7.3	2.70	6.20	1.20
23.0	0.0	-51.7	37.	15.	0.	4.09	4.05	0.	0.00008	3.00	7.3	2.50	6.00	1.10
23.0	0.0	-51.6	36.	16.	0.	4.06	4.02	0.	0.00008	2.00	7.0	2.30	6.00	0.90
0.0	0.0	-32.5	88.	-56.	0.	3.38	2.70	0.	-0.00025	2.70	6.9	2.50	5.80	0.70
0.0	0.0	-31.9	77.	-46.	0.	2.88	2.38	0.	-0.00020	2.50	7.0	2.20	5.60	0.70
0.0	0.0	-31.5	71.	-41.	0.	2.54	2.21	0.	-0.00016	2.10	7.1	1.40	5.40	0.30
1.0	0.0	-31.3	67.	-37.	0.	2.32	2.09	0.	-0.00016	1.80	7.0	0.90	5.30	0.10
1.0	0.0	-31.1	64.	-34.	0.	2.16	2.00	0.	-0.00015	1.80	7.0	1.20	5.40	0.00
1.0	0.0	-30.9	62.	-31.	0.	2.04	1.92	0.	-0.00014	1.90	7.0	1.40	5.30	0.10
2.0	0.0	-30.8	59.	-29.	0.	1.95	1.86	0.	-0.00013	1.70	6.9	0.10	5.20	0.10
2.0	0.0	-30.7	57.	-27.	0.	1.87	1.80	0.	-0.00012	1.70	6.9	-0.50	5.10	0.20
2.0	0.0	-30.5	55.	-26.	0.	1.81	1.74	0.	-0.00011	1.90	6.8	-0.50	5.00	0.60
3.0	0.0	-30.4	54.	-24.	0.	1.75	1.69	0.	-0.00010	2.20	6.7	-0.20	4.90	0.90
3.0	0.0	-30.4	52.	-23.	0.	1.70	1.64	0.	-0.00010	2.40	6.7	0.10	4.80	1.10
3.0	0.0	-30.3	51.	-21.	0.	1.65	1.60	0.	-0.00009	2.40	6.6	-0.20	4.80	1.30
4.0	0.0	-30.2	49.	-20.	0.	1.61	1.56	0.	-0.00009	2.50	6.5	-0.20	4.80	1.30
4.0	0.0	-30.1	48.	-19.	0.	1.57	1.53	0.	-0.00006	2.60	6.6	0.00	4.70	1.40
4.0	0.0	-30.0	47.	-18.	0.	1.53	1.49	0.	-0.00008	2.70	6.6	0.60	4.70	1.00
5.0	0.0	-30.0	46.	-17.	0.	1.49	1.46	0.	-0.00007	2.80	6.5	1.10	4.70	1.80
5.0	0.0	-29.9	45.	-16.	0.	1.46	1.43	0.	-0.00007	2.80	6.5	0.90	4.80	1.80
5.0	0.0	-29.9	44.	-15.	0.	1.43	1.40	0.	-0.00006	2.90	6.4	0.90	4.70	1.60
6.0	0.0	-27.5	13.	14.	0.	1.77	2.11	0.	0.00006	3.00	6.3	1.10	4.70	1.90
6.0	0.0	-27.8	18.	9.	0.	2.01	2.25	0.	0.00004	3.00	6.3	1.10	4.70	2.00
6.0	0.0	-27.9	20.	7.	0.	2.16	2.31	0.	0.00003	3.00	6.3	1.10	4.70	1.90
7.0	74.0	-16.5	14.	1.	0.	2.33	2.50	0.	0.00001	3.00	6.3	1.10	4.60	2.00
7.0	130.2	4.1	4.	-9.	0.	2.58	2.83	0.	-0.00004					
7.0	154.5	22.4	-3.	-20.	0.	2.88	3.18	0.	-0.00009	3.20	6.3	1.40	4.70	2.10
8.0	169.3	38.9	-9.	-31.	0.	3.20	3.51	0.	-0.00014	3.30	6.1	1.70	4.60	2.40
8.0	179.8	53.8	-13.	-41.	0.	3.51	3.83	0.	-0.00018	3.50	6.0	1.70	4.70	2.60
8.0	187.8	67.0	-17.	-51.	0.	3.82	4.13	0.	-0.00022	3.70	6.1	1.90	4.60	2.90
9.0	194.2	78.8	-20.	-60.	0.	4.12	4.41	0.	-0.00026	3.90	6.1	2.00	4.60	3.10
9.0	199.5	88.9	-22.	-68.	0.	4.39	4.66	0.	-0.00029	4.10	6.3	2.20	4.60	3.20
9.0	203.8	97.6	-23.	-75.	0.	4.64	4.89	0.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
10.0	207.4	105.0	-24.	-82.	0.	4.87	5.10	0.	-0.00035	4.60	6.4	3.00	4.80	4.00
10.0	210.3	111.0	-24.	-88.	0.	5.07	5.28	0.	-0.00038	5.10	6.4	3.50	4.90	4.10
10.0	212.6	115.8	-24.	-93.	0.	5.25	5.43	0.	-0.00040	5.30	6.4	3.80	5.00	4.50
11.0	214.4	119.5	-23.	-97.	0.	5.41	5.57	0.	-0.00042	5.40	6.2	4.10	5.10	5.00
11.0	215.6	122.0	-22.	-101.	0.	5.55	5.68	0.	-0.00044	5.80	6.2	4.40	5.20	5.20
11.0	216.3	123.5	-20.	-104.	0.	5.66	5.77	0.	-0.00045	5.90	6.2	4.80	5.20	5.50

Model Output 23-02-80 Actuals





23-24 FEBRUARY 1980



24-02-80

COMPUTED DATA
SAT. VAP. PRESSURE(MB)= 8.90
VAPOUR PRESSURE(MB)= 8.28
REL. HUMIDITY FRACTION = 0.93
APPROX. PRECIP. WATER(MM)= 13.0
ROAD DAMPING DEPTH(CM)= 72.
AIR DAMPING DEPTH(CM)= 2595. 1382.
AIR HEAT TRANSFER COEF.(CGS)= 0.00252 0.00081

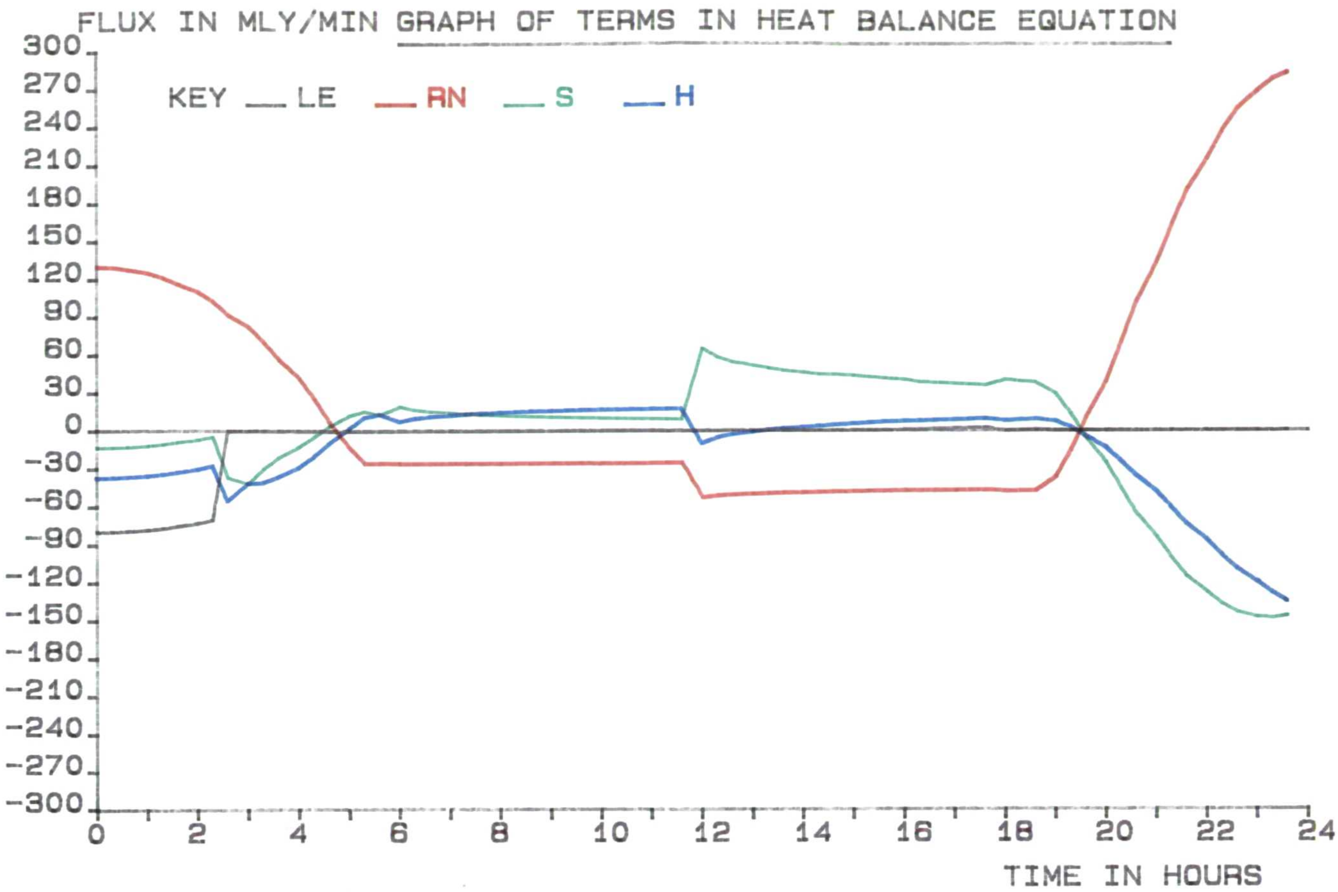
DEC	R	T36	T18	TS	UA	D	TIME WET
-9.309	0.990	279.4	278.5	6.5	418. 104.	0.5	12

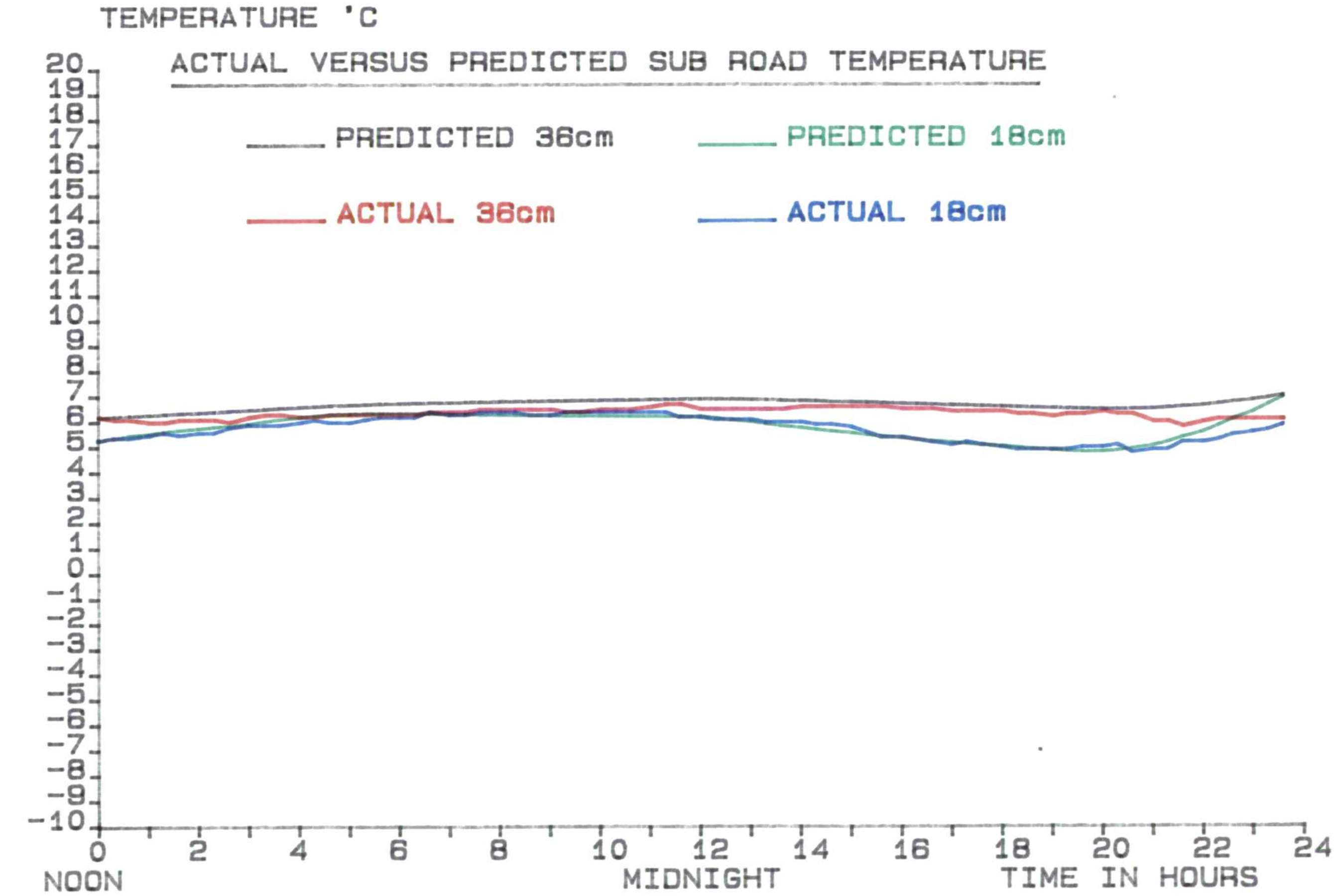
SOLAR TIME	SUN	RN	S	H	LE	TD	TC	SUM	KI
			(ALL MLY./MIN.)				(C.)		
12.0	216.6	129.7	-13.	-37.	-79.	6.50	6.58	-78.	-0.00011
12.0	216.4	129.1	-13.	-37.	-79.	6.54	6.58	-79.	-0.00011
12.0	215.6	127.5	-13.	-36.	-79.	6.55	6.56	-158.	-0.00010
13.0	214.4	124.8	-12.	-35.	-78.	6.54	6.54	-235.	-0.00010
13.0	212.7	121.0	-10.	-34.	-76.	6.52	6.50	-312.	-0.00010
13.0	210.4	116.0	-9.	-32.	-75.	6.49	6.45	-387.	-0.00009
14.0	207.5	109.7	-7.	-30.	-73.	6.44	6.40	-459.	-0.00009
14.0	203.9	102.1	-5.	-28.	-70.	6.38	6.32	-529.	-0.00008
14.0	199.6	91.3	-37.	-55.	0.	6.73	7.08	-529.	-0.00016
15.0	194.4	82.1	-42.	-41.	0.	7.12	7.50	-529.	-0.00012
15.0	188.0	69.9	-30.	-41.	0.	7.30	7.49	-529.	-0.00012
15.0	180.1	56.3	-21.	-36.	0.	7.33	7.36	-529.	-0.00010
16.0	169.7	41.4	-12.	-29.	0.	7.24	7.16	-529.	-0.00008
16.0	155.2	24.7	-4.	-20.	0.	7.08	6.92	-529.	-0.00006
16.0	131.4	6.4	4.	-10.	0.	6.86	6.63	-529.	-0.00003
17.0	77.8	-14.0	12.	2.	0.	6.58	6.31	-529.	0.00001
17.0	0.0	-26.2	16.	11.	0.	6.32	6.06	-529.	0.00003
17.0	0.0	-26.1	13.	13.	0.	6.16	5.99	-529.	0.00004
18.0	0.0	-26.6	19.	7.	0.	5.96	5.75	-529.	0.00002
18.0	0.0	-26.4	17.	10.	0.	5.82	5.69	-529.	0.00003
18.0	0.0	-26.4	15.	11.	0.	5.73	5.65	-529.	0.00003
19.0	0.0	-26.3	14.	12.	0.	5.68	5.62	-529.	0.00004
19.0	0.0	-26.3	13.	13.	0.	5.64	5.60	-529.	0.00004
19.0	0.0	-26.2	12.	14.	0.	5.61	5.58	-529.	0.00004
20.0	0.0	-26.2	12.	14.	0.	5.59	5.56	-529.	0.00004
20.0	0.0	-26.2	11.	15.	0.	5.57	5.55	-529.	0.00004
20.0	0.0	-26.1	11.	15.	0.	5.55	5.54	-529.	0.00004
21.0	0.0	-26.1	10.	16.	0.	5.54	5.53	-529.	0.00004
21.0	0.0	-26.1	10.	16.	0.	5.53	5.52	-529.	0.00005
21.0	0.0	-26.1	10.	16.	0.	5.52	5.51	-529.	0.00005
22.0	0.0	-26.1	10.	16.	0.	5.51	5.51	-529.	0.00005
22.0	0.0	-26.0	9.	17.	0.	5.51	5.50	-529.	0.00005
22.0	0.0	-26.0	9.	17.	0.	5.50	5.49	-529.	0.00005
23.0	0.0	-26.0	9.	17.	0.	5.50	5.49	-529.	0.00005
23.0	0.0	-26.0	9.	17.	0.	5.49	5.49	-529.	0.00005
23.0	0.0	-26.0	9.	17.	0.	5.49	5.48	-529.	0.00005
0.0	0.0	-53.5	65.	-10.	0.	4.80	4.12	-529.	-0.00130
0.0	0.0	-52.0	58.	-6.	0.	4.26	3.72	-529.	-0.00072
0.0	0.0	-51.1	54.	-3.	0.	3.86	3.49	-529.	-0.00038
1.0	0.0	-50.5	51.	-1.	0.	3.61	3.34	-529.	-0.00015
1.0	0.0	-50.1	49.	0.	0.	3.41	3.22	-529.	0.00003
1.0	0.0	-49.7	48.	1.	0.	3.27	3.12	-529.	0.00016
2.0	0.0	-49.3	46.	2.	0.	3.15	3.03	-529.	0.00031
2.0	0.0	-49.0	45.	3.	0.	3.05	2.95	-529.	0.00042
2.0	0.0	-48.7	44.	4.	0.	2.96	2.86	-529.	0.00056
3.0	0.0	-48.4	43.	5.	0.	2.87	2.79	-529.	0.00067
3.0	0.0	-48.2	42.	6.	0.	2.80	2.72	-529.	0.00077
3.0	0.0	-47.9	41.	7.	0.	2.73	2.66	-529.	0.00086
4.0	0.0	-47.8	40.	7.	1.	2.67	2.61	-528.	0.00093
4.0	0.0	-47.6	38.	8.	1.	2.62	2.58	-528.	0.00098
4.0	0.0	-47.5	38.	8.	1.	2.58	2.54	-526.	0.00104
5.0	0.0	-47.3	37.	9.	2.	2.54	2.50	-525.	0.00110
5.0	0.0	-47.2	36.	9.	2.	2.50	2.46	-523.	0.00116
5.0	0.0	-47.1	36.	9.	2.	2.46	2.42	-521.	0.00121
6.0	0.0	-48.1	40.	8.	0.	2.36	2.27	-521.	0.00100
6.0	0.0	-47.8	39.	9.	0.	2.28	2.20	-520.	0.00110
6.0	0.0	-47.6	38.	9.	1.	2.21	2.15	-520.	0.00116
7.0	68.6	-36.6	29.	7.	0.	2.26	2.30	-520.	0.00094
7.0	130.5	-15.4	13.	3.	0.	2.49	2.71	-520.	0.00034
7.0	179.8	10.0	-5.	-5.	0.	2.90	3.32	-520.	-0.00057
8.0	225.2	39.0	-25.	-14.	0.	3.49	4.09	-520.	-0.00170
8.0	267.5	69.8	-46.	-24.	0.	4.23	4.97	-520.	-0.00306
8.0	307.1	101.3	-65.	-36.	0.	5.08	5.93	-520.	-0.00442
9.0	344.2	132.7	-84.	-48.	0.	6.02	6.96	-520.	-0.00592
9.0	376.0	162.5	-101.	-61.	0.	7.01	8.00	-520.	-0.00744
9.0	408.6	190.2	-116.	-74.	0.	8.02	9.03	-520.	-0.00894
10.0	435.8	216.2	-128.	-87.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
10.0	459.1	236.7	-138.	-99.	0.	10.00	10.97	-520.	-0.01176
10.0	478.5	254.5	-145.	-110.	0.	10.92	11.84	-520.	-0.01300
11.0	493.9	268.4	-148.	-120.	0.	11.77	12.61	-520.	-0.01412
11.0	504.9	277.9	-149.	-129.	0.	12.52	13.28	-520.	-0.01508
11.0	511.5	283.0	-147.	-136.	0.	13.18	13.83	-520.	-0.01586

Model Output 24-02-80

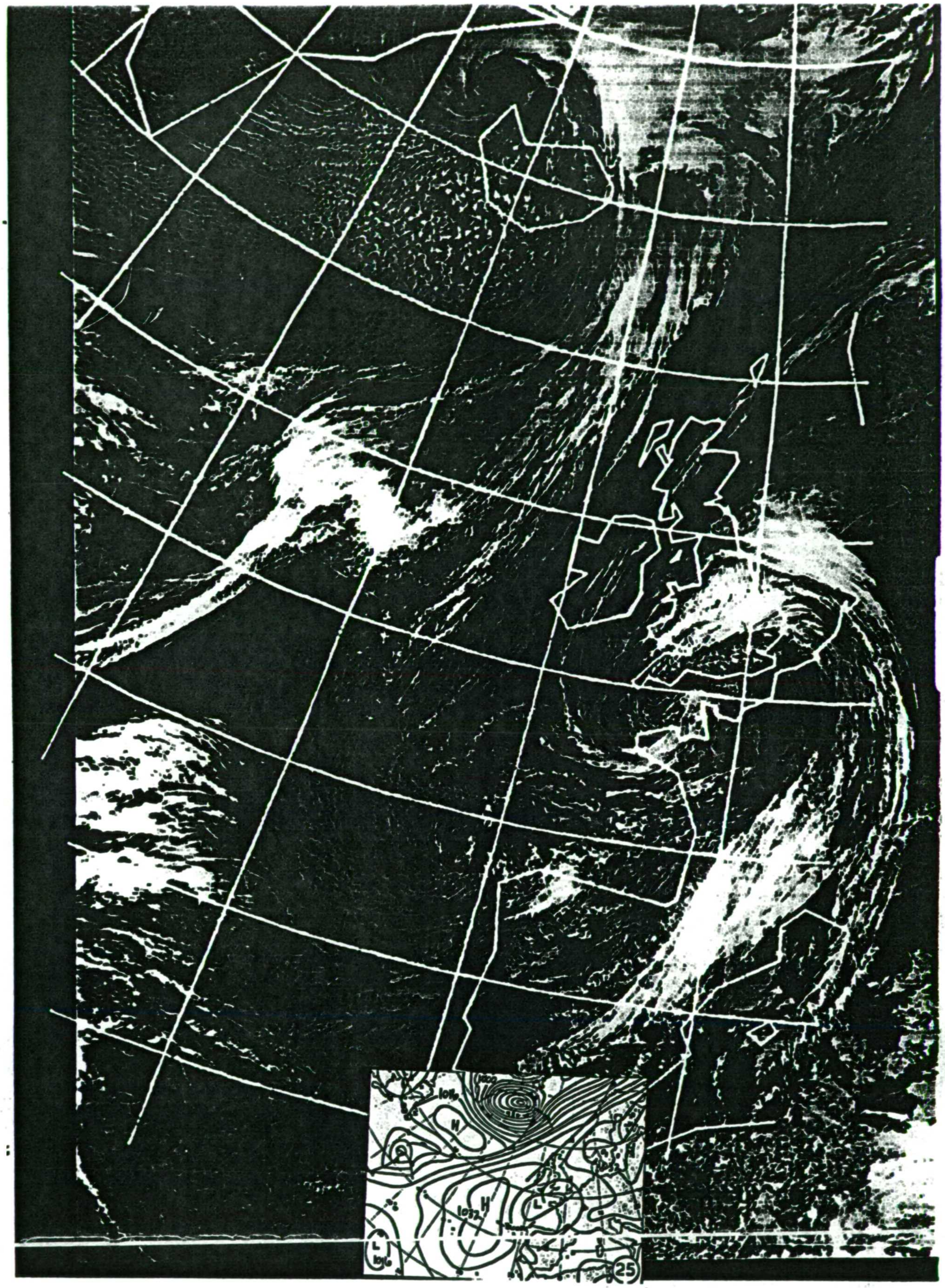
TO	T36	Air	T18	Tslab
6.50	6.2	5.00	5.30	6.10
6.00	6.1	4.90	5.40	5.40
5.90	6.1	5.00	5.40	5.10
5.80	6.0	5.10	5.50	5.10
5.80	6.0	5.10	5.60	5.10
5.90	6.1	5.40	5.50	5.20
6.10	6.1	5.60	5.60	5.30
6.10	6.1	5.60	5.60	5.30
6.30	6.0	5.80	5.80	5.50
6.10	6.2	6.10	5.90	5.70
6.60	6.3	6.20	5.90	5.70
6.70	6.3	6.20	5.90	5.60
6.50	6.2	6.10	6.00	5.50
6.40	6.2	6.30	6.10	5.60
6.50	6.3	6.10	6.00	5.40
6.50	6.3	5.90	6.00	5.30
6.50	6.3	6.00	6.10	5.30
6.50	6.3	6.10	6.20	5.40
6.50	6.3	6.10	6.20	5.40
6.50	6.3	6.20	6.20	5.40
6.50	6.4	6.20	6.40	5.40
6.60	6.4	6.30	6.30	5.50
6.60	6.4	6.50	6.30	5.50
6.60	6.5	6.30	6.40	5.50
6.60	6.5	6.40	6.40	5.50
6.60	6.5	6.40	6.40	5.60
6.60	6.5	6.50	6.30	5.60
6.30	6.5	5.80	6.30	5.30
6.20	6.4	5.60	6.40	5.30
6.10	6.4	5.50	6.40	5.20
6.00	6.5	5.30	6.40	5.20
5.90	6.5	5.00	6.40	5.00
5.70	6.5	4.80	6.40	4.80
5.70	6.6	4.90	6.40	4.90
5.70	6.7	4.70	6.40	4.80
5.50	6.7	4.50	6.20	4.70
5.20	6.5	4.30	6.20	4.40
5.10	6.5	4.30	6.10	4.40
5.10	6.5	4.40	6.10	4.30
5.00	6.5	4.20	6.10	4.30
4.80	6.5	4.10	6.00	4.00
4.70	6.5	4.00	6.00	3.90
4.20	6.6	3.00	6.00	3.10
3.80	6.6	3.20	5.90	2.60
3.40	6.6	3.40	5.90	2.20
3.10	6.6	2.30	5.80	1.90
2.90	6.6	1.90	5.00	1.80
2.80	6.6	1.80	5.40	1.40
2.70	6.5	1.70	5.40	1.00
3.00	6.5	2.60	5.30	2.10
3.20	6.5	2.60	5.20	2.40
3.40	6.4	2.80	5.10	2.60
3.00	6.4	2.00	5.20	2.00
3.20	6.4	2.30	5.10	2.40
3.40	6.4	2.00	5.00	2.50
3.50	6.3	1.70	4.90	2.60
3.40	6.3	1.90	4.90	2.50
3.60	6.2	2.10	4.90	2.80
3.60	6.3	1.80	4.90	2.70
3.70	6.3	1.70	5.00	2.80
3.90	6.4	1.70	5.00	3.20
4.30	6.3	2.20	5.10	3.40
4.60	6.3	2.70	4.80	4.00
4.70	6.0	2.60	4.90	4.20
5.30	6.0	2.80	4.90	5.20
5.50	5.8	3.30	[illegible]	[illegible]
6.00	6.0	3.50	5.20	6.10
6.60	6.1	4.00	5.30	6.70
6.90	6.1	3.40	5.50	6.90
7.40	6.1	3.70	5.60	7.40
7.60	6.1	4.10	5.70	7.90
8.10	6.1	4.60	5.90	8.70

Actuals





24-25 FEBRUARY 1980



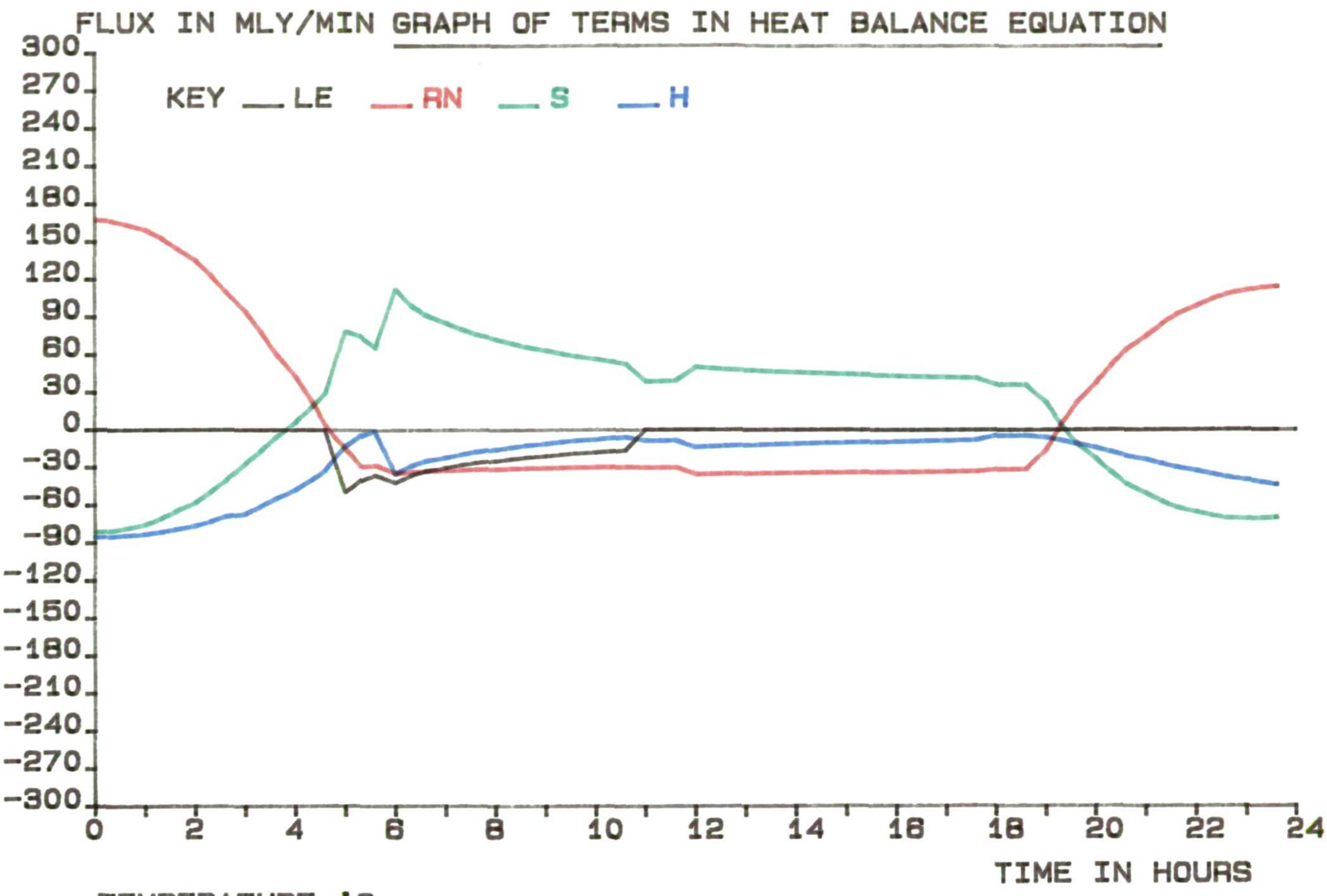
25-02-80

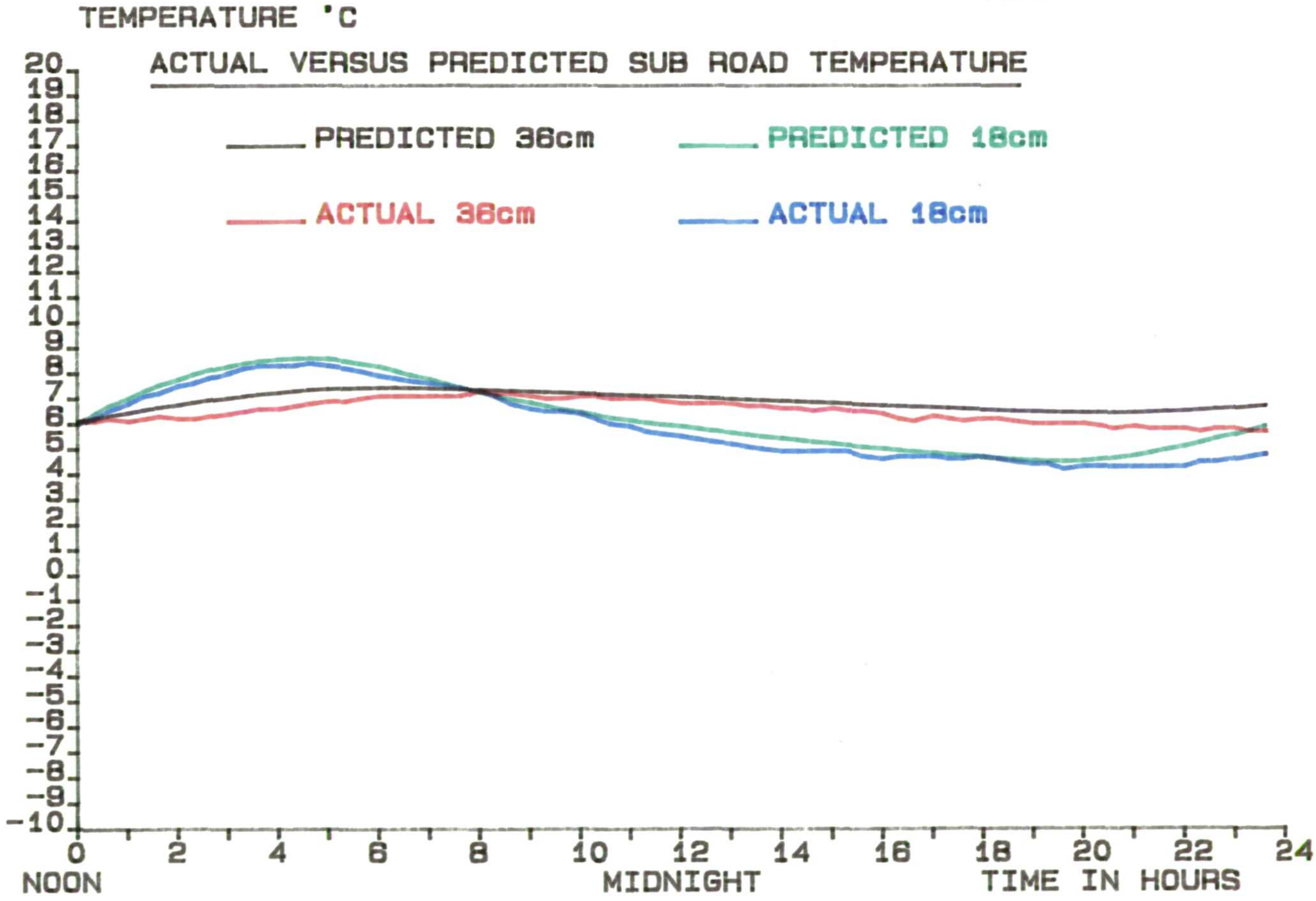
COMPUTED DATA
SAT. VAP. PRESSURE(MB)= 9.94
VAPOUR PRESSURE(MB)= 8.65
REL. HUMIDITY FRACTION = 0.87
APPROX. PRECIP. WATER(MM)= 13.6
ROAD DAMPING DEPTH(CM)= 72.
AIR DAMPING DEPTH(CM)= 1400. 705.
AIR HEAT TRANSFER COEF.(CGS)= 0.00083 0.00025

DEC	K	T36	T18	TS	UA	D	TIME WET
-8.937	0.990	279.3	279.2	10.2	107. 23.	0.5	17

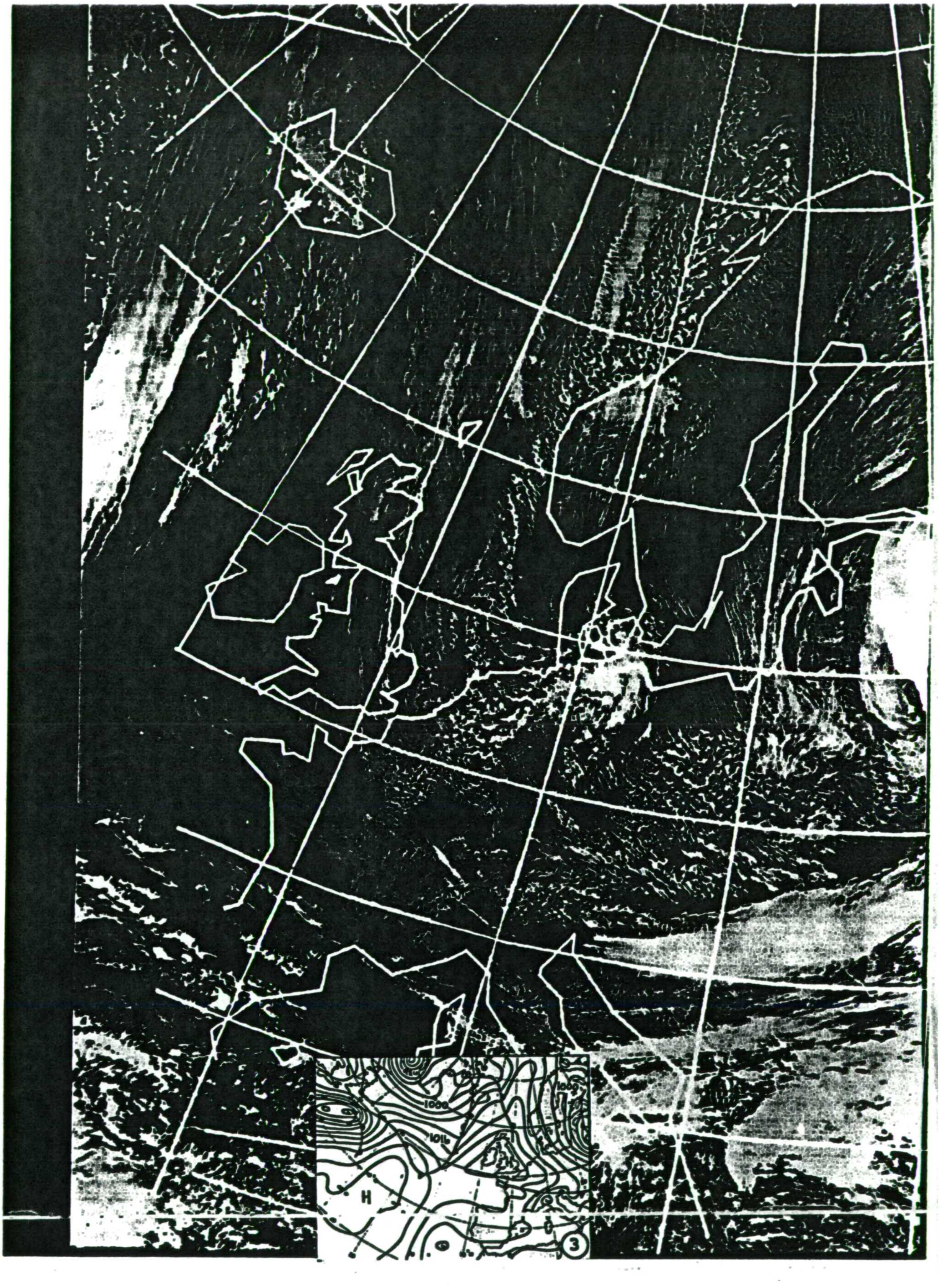
SOLAR TIME	SUN	RN	S	H	LE	TD	TC	SUM	RI	TO	T36	Air	T18	Tslab
			(ALL MLY./MIN.)				(C.)							
12.0	283.7	167.0	-82.	-85.	0.	10.20	13.90	1.	-0.00939	10.20	6.10	5.50	6.00	11.70
12.0	283.1	166.1	-81.	-85.	0.	12.04	13.88	0.	-0.00937	11.60	6.10	5.80	6.20	13.30
12.0	281.1	163.4	-79.	-84.	0.	12.93	13.82	0.	-0.00929	11.60	6.20	6.20	6.50	13.00
13.0	278.0	158.9	-76.	-83.	0.	13.33	13.74	0.	-0.00917	11.90	6.10	7.40	6.80	13.60
13.0	273.5	152.6	-71.	-82.	0.	13.47	13.61	0.	-0.00900	12.30	6.20	7.20	7.10	13.80
13.0	267.8	144.5	-65.	-79.	0.	13.45	13.44	0.	-0.00877	11.70	6.30	7.00	7.20	12.70
14.0	260.6	134.7	-58.	-77.	0.	13.34	13.22	0.	-0.00847	11.30	6.20	7.40	7.50	12.50
14.0	252.5	123.2	-50.	-73.	0.	13.14	12.95	0.	-0.00811	10.80	6.20	7.30	7.60	12.00
14.0	242.9	110.0	-41.	-69.	0.	12.89	12.63	0.	-0.00767	12.20	6.30	8.00	7.80	14.00
15.0	232.5	94.2	-27.	-67.	0.	12.52	12.16	0.	-0.00745	12.10	6.40	7.90	8.00	13.20
15.0	219.9	78.1	-17.	-61.	0.	12.11	11.71	0.	-0.00683	11.20	6.50	7.90	8.20	12.10
15.0	205.4	60.6	-6.	-55.	0.	11.66	11.21	0.	-0.00616	11.00	6.60	7.80	8.30	11.70
16.0	188.7	42.2	6.	-48.	0.	11.16	10.65	0.	-0.00539	10.30	6.60	7.60	8.30	10.80
16.0	167.9	22.9	18.	-40.	0.	10.60	10.05	0.	-0.00457	9.60	6.70	6.40	8.30	9.40
16.0	139.3	3.0	30.	-33.	0.	10.01	9.41	0.	-0.00369	8.90	6.80	6.10	8.40	8.60
17.0	86.6	-15.7	78.	-13.	-50.	8.93	7.85	-50.	-0.00154	8.50	6.90	5.70	8.30	8.00
17.0	0.0	-29.2	74.	-5.	-40.	8.05	7.16	-90.	-0.00058	7.60	6.90	5.20	8.20	7.20
17.0	0.0	-28.5	65.	-1.	-36.	7.44	6.83	-126.	-0.00012	7.10	7.00	5.00	8.10	6.60
18.0	0.0	-34.8	112.	-35.	-42.	6.38	5.33	-168.	-0.00405	6.80	7.10	4.80	7.90	5.90
18.0	0.0	-33.7	99.	-29.	-36.	5.61	4.83	-205.	-0.00336	6.80	7.10	5.10	7.80	5.90
18.0	0.0	-33.1	91.	-25.	-33.	5.06	4.52	-238.	-0.00291	6.40	7.10	4.50	7.70	5.40
19.0	0.0	-32.6	85.	-22.	-30.	4.67	4.28	-268.	-0.00258	6.20	7.10	4.80	7.60	5.00
19.0	0.0	-32.1	80.	-20.	-28.	4.38	4.08	-297.	-0.00231	5.70	7.10	4.20	7.50	4.40
19.0	0.0	-31.8	76.	-18.	-26.	4.15	3.91	-323.	-0.00207	5.30	7.10	3.70	7.40	4.10
20.0	0.0	-31.5	72.	-16.	-25.	3.95	3.76	-348.	-0.00186	5.10	7.30	3.60	7.30	3.80
20.0	0.0	-31.2	69.	-14.	-23.	3.79	3.63	-371.	-0.00167	4.80	7.20	3.10	7.10	3.50
20.0	0.0	-30.9	66.	-13.	-22.	3.65	3.51	-394.	-0.00150	4.50	7.20	2.20	6.80	3.20
21.0	0.0	-30.7	63.	-11.	-21.	3.52	3.39	-415.	-0.00134	3.90	7.10	2.00	6.60	2.60
21.0	0.0	-30.5	60.	-10.	-20.	3.41	3.29	-435.	-0.00120	3.60	7.00	0.90	6.50	2.20
21.0	0.0	-30.3	58.	-9.	-19.	3.30	3.20	-454.	-0.00107	3.30	7.00	0.80	6.50	2.00
22.0	0.0	-30.1	56.	-8.	-18.	3.21	3.11	-472.	-0.00094	3.30	7.10	0.70	6.40	1.90
22.0	0.0	-29.9	54.	-7.	-17.	3.12	3.03	-489.	-0.00083	3.00	7.10	0.40	6.20	1.60
22.0	0.0	-29.8	52.	-6.	-17.	3.04	2.96	-506.	-0.00073	2.80	7.00	0.40	6.00	1.40
23.0	0.0	-30.3	38.	-9.	0.	3.11	3.19	-506.	-0.00105	2.60	7.00	0.70	5.90	1.30
23.0	0.0	-30.3	38.	-9.	0.	3.16	3.20	-506.	-0.00107	2.40	7.00	0.40	5.70	1.00
23.0	0.0	-30.2	39.	-9.	0.	3.16	3.17	-506.	-0.00102	2.50	6.90	-0.10	5.60	1.20
0.0	0.0	-35.7	50.	-14.	0.	3.01	2.85	-506.	-0.08269	2.40	6.80	-0.80	5.50	1.10
0.0	0.0	-35.4	49.	-14.	0.	2.86	2.71	-506.	-0.07899	2.00	6.60	-1.10	5.40	0.80
0.0	0.0	-35.2	48.	-13.	0.	2.73	2.60	-506.	-0.07614	2.20	6.60	-0.50	5.30	1.10
1.0	0.0	-35.0	47.	-13.	0.	2.62	2.50	-506.	-0.07372	2.40	6.60	-0.60	5.20	1.40
1.0	0.0	-34.8	47.	-12.	0.	2.52	2.42	-506.	-0.07153	2.50	6.70	-0.20	5.10	1.50
1.0	0.0	-34.6	46.	-12.	0.	2.43	2.34	-506.	-0.06948	2.50	6.70	-0.50	5.00	1.50
2.0	0.0	-34.5	46.	-11.	0.	2.35	2.27	-506.	-0.06755	2.50	6.60	-0.40	4.90	1.60
2.0	0.0	-34.3	45.	-11.	0.	2.27	2.19	-506.	-0.06570	2.60	6.60	0.00	4.90	1.80
2.0	0.0	-34.2	45.	-11.	0.	2.20	2.13	-506.	-0.06392	2.60	6.50	-0.20	4.90	1.80
3.0	0.0	-34.0	44.	-10.	0.	2.13	2.06	-506.	-0.06221	2.80	6.60	0.00	4.90	2.00
3.0	0.0	-33.9	44.	-10.	0.	2.06	2.00	-506.	-0.06056	2.80	6.50	0.10	4.90	2.10
3.0	0.0	-33.8	43.	-10.	0.	2.00	1.94	-506.	-0.05897	2.90	6.50	0.20	4.70	2.10
4.0	0.0	-33.7	43.	-9.	0.	1.94	1.88	-506.	-0.05744	2.70	6.40	0.00	4.60	1.60
4.0	0.0	-33.5	42.	-9.	0.	1.88	1.82	-506.	-0.05596	2.70	6.20	-0.20	4.70	1.60
4.0	0.0	-33.4	42.	-9.	0.	1.82	1.76	-506.	-0.05453	2.60	6.10	-0.30	4.70	1.80
5.0	0.0	-33.3	42.	-9.	0.	1.77	1.71	-506.	-0.05315	2.60	6.30	-0.50	4.70	1.80
5.0	0.0	-33.2	41.	-8.	0.	1.71	1.66	-506.	-0.05181	2.50	6.20	-0.60	4.60	1.70
5.0	0.0	-33.1	41.	-8.	0.	1.66	1.61	-506.	-0.05052	2.30	6.10	-0.90	4.60	1.60
6.0	0.0	-31.4	36.	-5.	0.	1.67	1.68	-506.	-0.03140	2.30	6.20	-0.70	4.70	1.60
6.0	0.0	-31.4	36.	-5.	0.	1.67	1.67	-506.	-0.03126	2.20	6.20	-0.70	4.60	1.40
6.0	0.0	-31.4	36.	-5.	0.	1.66	1.65	-506.	-0.03075	2.30	6.10	-0.30	4.50	1.50
7.0	90.5	-15.8	21.	-6.	0.	1.81	1.97	-506.	-0.03866	2.30	6.00	-0.10	4.40	1.60
7.0	136.3	4.0	4.	-9.	0.	2.15	2.49	-506.	-0.05245	2.20	6.00	-0.30	4.40	1.60
7.0	158.0	21.5	-10.	-11.	0.	2.61	3.08	-506.	-0.06762	2.40	6.00	-0.20	4.20	1.90
8.0	171.8	37.3	-23.	-14.	0.	3.15	3.69	-506.	-0.08332	2.30	6.00	-0.60	4.30	1.70
8.0	181.7	51.4	-34.	-18.	0.	3.72	4.29	-506.	-0.09893	2.40	5.90	-0.30	4.30	2.20
8.0	169.4	63.9	-43.	-21.	0.	4.30	4.88	-506.	-0.11412	2.70	5.80	-0.10	4.30	2.50
9.0	195.7	74.8	-51.	-24.	0.	4.88	5.45	-506.	-0.12874	3.20	5.90	0.20	4.30	3.10
9.0	200.8	84.2	-57.	-27.	0.	5.44	5.99	-506.	-0.14258	3.30	5.80	0.70	4.30	3.60
9.0	205.0	92.1	-62.	-30.	0.	5.97	6.50	-506.	-0.15557	3.70	5.80	0.80	4.30	4.00
10.0	208.5	98.8	-66.	-33.	0.	6.47	6.98	-506.	[illegible]	[illegible]	[illegible]	-0.70	[illegible]	4.00
10.0	211.3	104.2	-69.	-36.	0.	6.95	7.42	-506.	-0.17686	4.40	5.70	0.00	4.50	5.20
10.0	213.6	108.3	-71.	-38.	0.	7.39	7.83	-506.	-0.18935	4.80	5.80	1.20	4.50	5.80
11.0	215.4	111.5	-71.	-40.	0.	7.79	8.19	-506.	-0.19850	5.40	5.80	1.20	4.60	6.50
11.0	216.6	113.5	-71.	-42.	0.	8.15	8.51	-506.	-0.20656	6.10	5.70	2.10	4.70	7.10
11.0	217.3	114.5	-70.	-44.	0.	8.47	8.79	-506.	-0.21359	6.30	5.70	2.10	4.80	7.50

Model Output 25-02-80 Actuals





25-26 FEBRUARY 1980



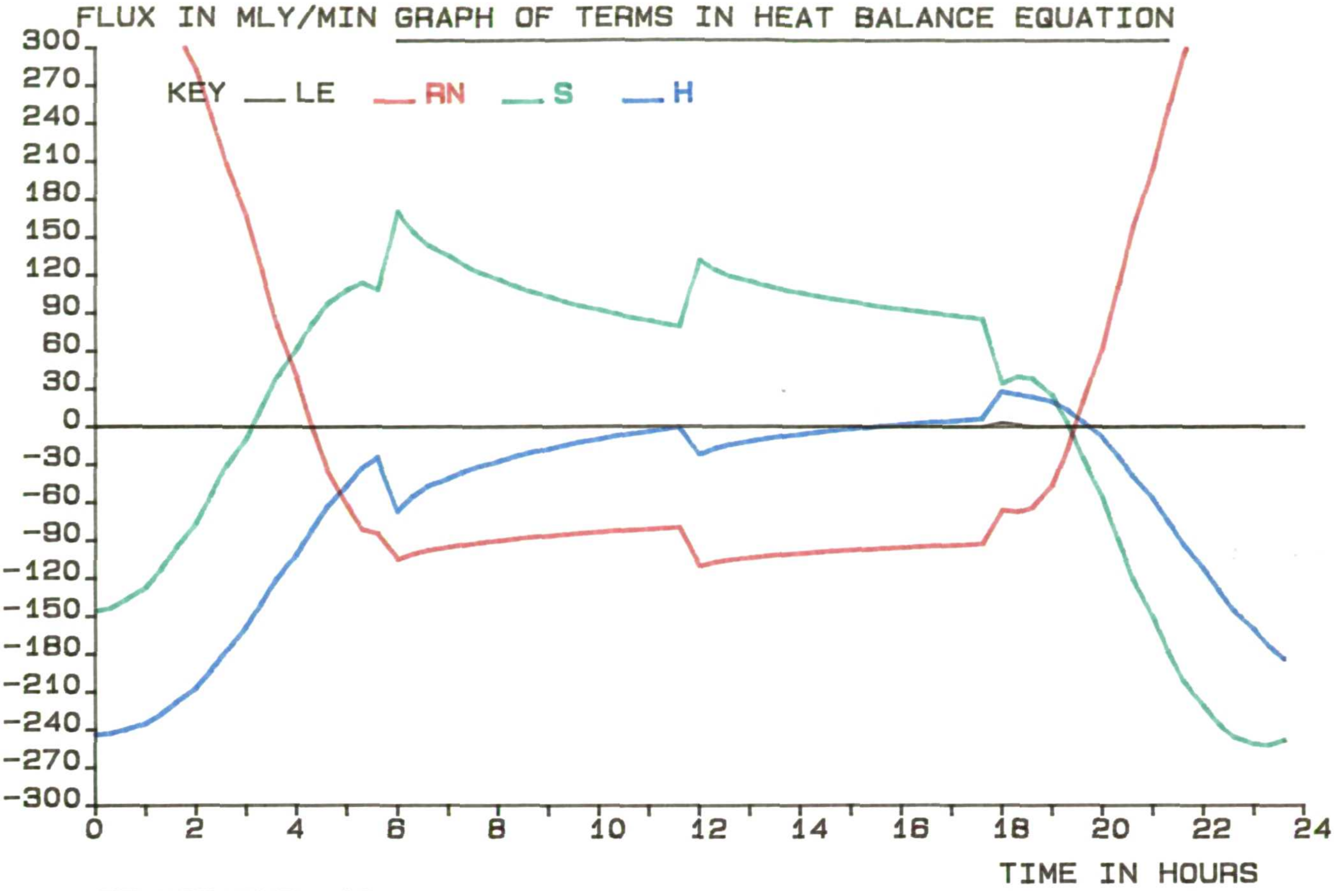
03-03-80

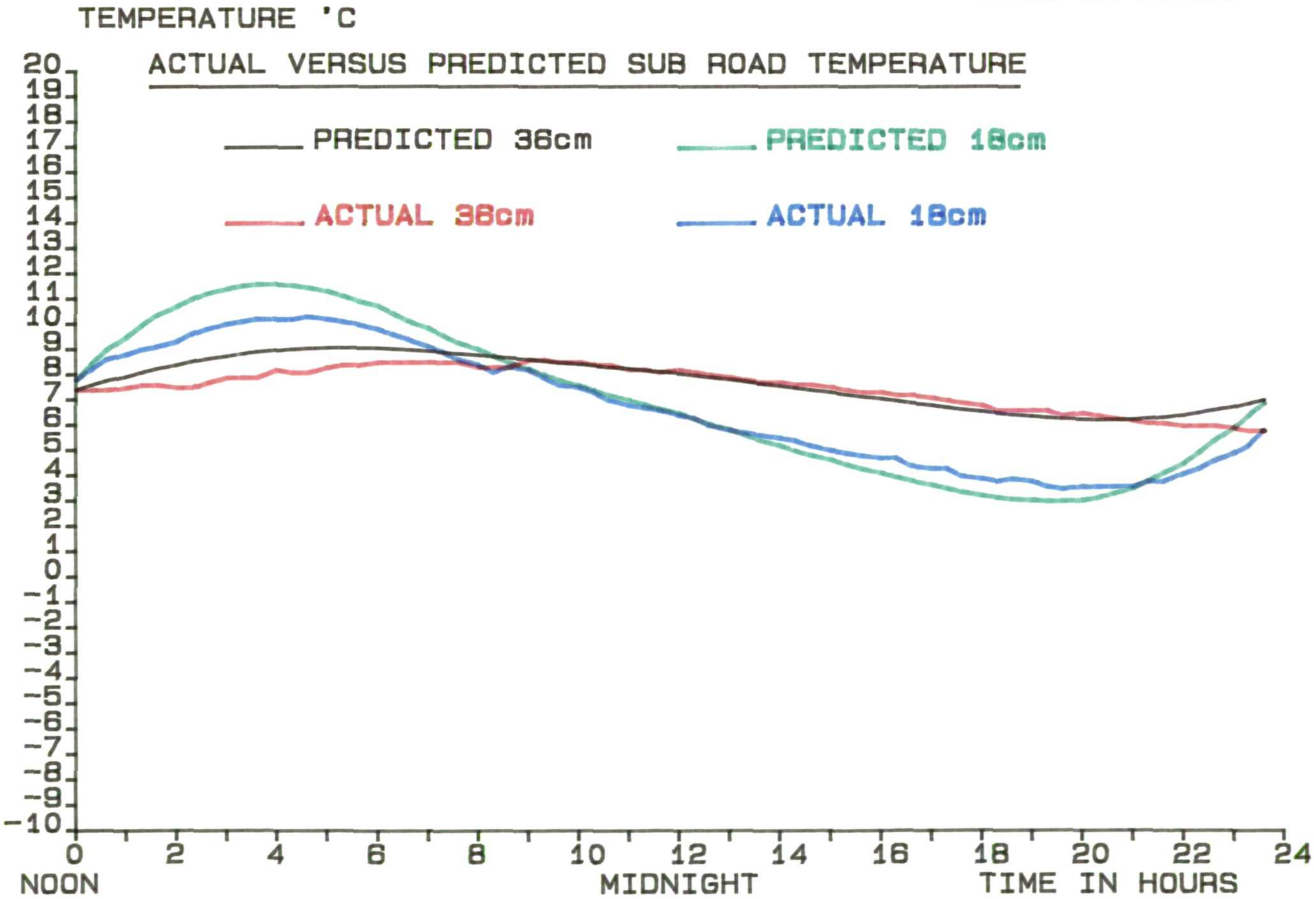
COMPUTED DATA
SAT. VAP. PRESSURE(MB)= 9.41
VAPOUR PRESSURE(MB)= 5.08
REL. HUMIDITY FRACTION = 0.54
APPROX. PRECIP. WATER(MM)= 8.2
ROAD DAMPING DEPTH(CM)= 72.
AIR DAMPING DEPTH(CM)= 1575. 1215.
AIR HEAT TRANSFER COEF.(CGS)= 0.00103 0.00065

DEC	R	T36	T18	TS	UA	D	TIME WET
-6.280	0.99228	0.62	81.0	13.3 139.	78.	0.5	0

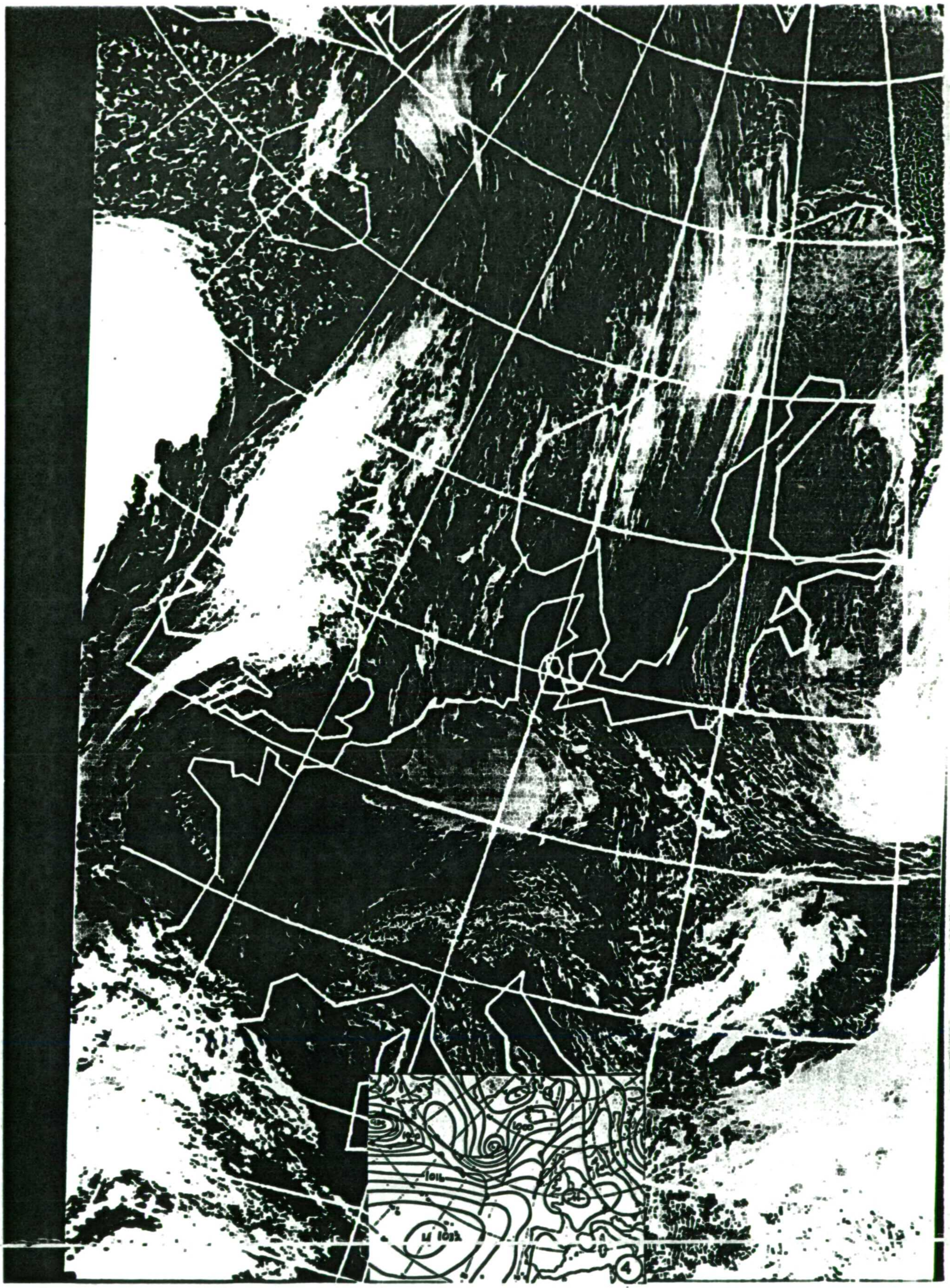
SOLAR TIME	SUN	RN	S	H	LE	TD	TC (C.)	SUM	KI	TO	T36	Air	T18	Tsla
		(ALL	LY./MIN.)											
12.0	715.3	388.5	-145.	-243.	0.	13.30	21.87	1.	-0.01283	13.30	7.40	5.50	7.80	14.3
12.0	712.2	385.4	-143.	-242.	0.	17.56	21.81	0.	-0.01279	13.50	7.40	5.80	8.20	15.4
12.0	702.9	376.1	-137.	-239.	0.	19.60	21.64	0.	-0.01265	13.70	7.40	6.10	8.00	15.6
13.0	687.9	361.1	-127.	-235.	0.	20.47	21.34	0.	-0.01241	14.10	7.50	5.70	8.80	16.3
13.0	666.6	340.1	-113.	-227.	0.	20.68	20.90	0.	-0.01200	14.40	7.60	6.50	9.00	16.8
13.0	639.5	313.7	-96.	-218.	0.	20.51	20.33	0.	-0.01160	14.40	7.60	6.50	9.10	17.1
14.0	607.3	282.7	-76.	-207.	0.	20.06	19.62	0.	-0.01103	14.40	7.50	6.40	9.30	17.0
14.0	569.6	247.2	-54.	-193.	0.	19.42	18.77	0.	-0.01035	14.40	7.50	5.90	9.60	17.0
14.0	527.0	208.1	-30.	-178.	0.	18.61	17.80	0.	-0.00956	14.30	7.70	6.10	9.80	16.9
15.0	479.8	167.3	-9.	-158.	0.	17.69	16.78	0.	-0.00856	14.10	7.90	6.40	10.00	16.4
15.0	428.7	124.0	16.	-140.	0.	16.66	15.62	0.	-0.00761	13.70	7.90	6.70	10.10	16.2
15.0	374.0	80.7	40.	-121.	0.	15.52	14.38	0.	-0.00660	13.10	7.90	6.50	10.20	15.8
16.0	316.4	38.8	62.	-101.	0.	14.32	13.12	0.	-0.00556	12.40	8.20	6.20	10.20	14.5
16.0	255.8	-0.2	82.	-81.	0.	13.09	11.86	0.	-0.00452	12.00	8.10	6.40	10.20	14.0
16.0	192.5	-34.4	98.	-63.	0.	11.88	10.66	0.	-0.00353	11.30	8.10	6.40	10.30	13.3
17.0	125.7	-61.8	109.	-47.	0.	10.73	9.58	0.	-0.00262	10.80	8.30	6.50	10.20	11.8
17.0	43.9	-81.2	114.	-33.	0.	9.70	8.66	0.	-0.00185	10.00	8.40	6.10	10.10	10.6
17.0	0.0	-84.4	108.	-24.	0.	8.88	8.07	0.	-0.00136	9.10	8.40	5.20	10.00	9.7
18.0	0.0	-104.6	171.	-66.	0.	7.43	5.97	0.	-0.00370	8.20	8.50	4.60	9.80	8.7
18.0	0.0	-100.1	155.	-55.	0.	6.31	5.20	0.	-0.00311	7.60	8.50	4.70	9.60	7.9
18.0	0.0	-97.1	144.	-47.	0.	5.49	4.68	0.	-0.00267	7.10	8.50	4.30	9.40	7.3
19.0	0.0	-94.9	135.	-41.	0.	4.89	4.28	0.	-0.00233	6.60	8.50	3.90	9.10	6.5
19.0	0.0	-92.9	128.	-36.	0.	4.41	3.94	0.	-0.00204	6.30	8.50	3.80	8.90	6.1
19.0	0.0	-91.3	122.	-31.	0.	4.03	3.65	0.	-0.00179	5.80	8.50	2.50	8.60	5.6
20.0	0.0	-89.6	117.	-27.	0.	3.71	3.38	0.	-0.00156	5.30	8.30	1.90	8.40	5.0
20.0	0.0	-88.4	112.	-24.	0.	3.42	3.14	0.	-0.00136	4.70	8.30	0.50	8.10	4.5
20.0	0.0	-87.2	107.	-20.	0.	3.17	2.92	0.	-0.00117	4.40	8.30	1.00	8.30	4.1
21.0	0.0	-86.1	103.	-17.	0.	2.95	2.72	0.	-0.00100	3.60	8.60	-0.50	8.20	4.1
										3.30	8.60	0.20	7.90	3.7
21.0	0.0	-85.1	99.	-15.	0.	2.74	2.54	0.	-0.00084	3.00	8.50	0.90	7.60	3.6
21.0	0.0	-84.1	96.	-12.	0.	2.55	2.36	0.	-0.00069	2.70	8.50	0.30	7.50	3.2
22.0	0.0	-83.2	93.	-10.	0.	2.38	2.20	0.	-0.00056	2.50	8.40	0.10	7.30	2.9
22.0	0.0	-82.4	90.	-7.	0.	2.22	2.06	0.	-0.00043	2.20	8.40	0.10	7.00	2.6
22.0	0.0	-81.6	87.	-5.	0.	2.07	1.92	0.	-0.00031	2.20	8.20	-0.80	6.80	2.2
23.0	0.0	-80.9	84.	-3.	0.	1.93	1.79	0.	-0.00020	2.00	8.20	-1.00	6.70	2.0
23.0	0.0	-80.3	82.	-2.	0.	1.80	1.67	0.	-0.00010	1.80	8.10	-1.10	6.60	1.6
23.0	0.0	-79.6	79.	0.	0.	1.68	1.56	0.	0.00000	1.50	8.20	-0.40	6.40	1.7
0.0	0.0	-110.3	132.	-22.	0.	0.90	0.12	0.	-0.00598	1.30	8.10	-0.90	6.30	1.4
0.0	0.0	-107.2	124.	-17.	0.	0.26	-0.38	0.	-0.00468	1.10	8.00	-1.00	6.00	1.2
0.0	0.0	-105.2	119.	-14.	0.	-0.23	-0.71	0.	-0.00381	1.10	7.90	-2.20	5.80	1.0
1.0	0.0	-103.7	115.	-11.	0.	-0.60	-0.97	0.	-0.00315	0.90	7.80	-2.00	5.70	0.7
1.0	0.0	-102.4	112.	-9.	0.	-0.89	-1.18	0.	-0.00259	0.80	7.70	-2.60	5.60	0.5
1.0	0.0	-101.3	109.	-8.	0.	-1.13	-1.38	0.	-0.00209	0.70	7.70	-2.30	5.50	0.5
2.0	0.0	-100.2	106.	-6.	0.	-1.34	-1.55	0.	-0.00164	0.60	7.60	-2.00	5.40	0.3
2.0	0.0	-99.3	104.	-4.	0.	-1.53	-1.71	0.	-0.00121	0.40	7.60	-2.40	5.20	0.2
2.0	0.0	-98.4	101.	-3.	0.	-1.70	-1.87	0.	-0.00081	0.30	7.50	-2.60	5.00	0.1
3.0	0.0	-97.5	99.	-2.	0.	-1.85	-2.01	0.	-0.00044	0.20	7.40	-2.50	4.90	0.0
3.0	0.0	-96.7	97.	0.	0.	-2.00	-2.15	0.	-0.00009	0.10	7.30	-3.00	4.80	-0.3
3.0	0.0	-95.9	95.	1.	0.	-2.14	-2.27	0.	0.00025	0.00	7.30	-2.70	4.70	-0.4
4.0	0.0	-95.2	93.	2.	0.	-2.27	-2.39	0.	0.00056	-0.10	7.20	-3.30	4.70	-0.6
4.0	0.0	-94.6	91.	3.	0.	-2.39	-2.51	0.	0.00086	-0.20	7.20	-2.60	4.40	-0.7
4.0	0.0	-93.9	90.	4.	0.	-2.50	-2.62	0.	0.00115	-0.40	7.10	-2.70	4.30	-0.7
5.0	0.0	-93.3	88.	5.	0.	-2.61	-2.72	0.	0.00142	-0.50	7.00	-3.30	4.30	-0.9
5.0	0.0	-92.7	87.	6.	0.	-2.72	-2.82	0.	0.00168	-0.50	6.90	-2.60	4.00	-1.1
5.0	0.0	-92.2	85.	7.	0.	-2.82	-2.92	0.	0.00193	-0.30	6.80	-3.20	3.90	-1.4
6.0	0.0	-65.7	35.	28.	3.	-2.31	-1.81	3.	0.00812	-0.10	6.60	-2.90	3.80	-1.4
6.0	0.0	-67.0	40.	26.	1.	-1.94	-1.56	5.	0.00747	0.00	6.60	-3.00	3.90	-1.5
6.0	31.5	-63.4	39.	24.	0.	-1.65	-1.37	5.	0.00698	0.60	6.60	-2.80	3.80	-1.3
7.0	99.5	-45.9	25.	20.	0.	-1.29	-0.94	5.	0.00585	1.30	6.60	-2.50	3.60	-1.2
7.0	170.9	-17.4	4.	14.	0.	-0.75	-0.20	5.	0.00394					
7.0	243.6	19.7	-24.	5.	0.	0.04	0.83	5.	0.00127	2.20	6.40	-2.30	3.50	-1.1
8.0	315.8	63.1	-56.	-8.	0.	1.08	2.12	5.	-0.00207	3.10	6.50	-1.50	3.00	-0.2
8.0	385.5	109.9	-88.	-22.	0.	2.35	3.62	5.	-0.00590	4.10	6.40	-0.90	3.00	0.6
8.0	452.0	158.0	-120.	-38.	0.	3.80	5.25	5.	-0.01000	5.20	6.30	-0.20	3.00	2.0
9.0	514.9	206.0	-150.	-56.	0.	5.39	6.98	5.	-0.01443	6.30	6.20	0.60	3.00	3.1
9.0	572.7	251.7	-178.	-74.	0.	7.06	8.72	5.	-0.01884	7.00	6.10	1.50	3.80	4.0
9.0	625.2	294.0	-201.	-93.	0.	8.75	10.44	5.	-0.02313	8.90	6.10	2.50	3.80	6.2
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.	10.43	12.11	5.	-0.02730	10.10	[illegible]	3.70	[illegible]	[illegible]
10.0	712.6	364.4	-235.	-129.	0.	12.06	13.68	5.	-0.03118	11.20	6.00	4.70	4.30	9.0
10.0	746.1	390.8	-246.	-145.	0.	13.59	15.12	5.	-0.03472	12.20	6.00	6.00	4.00	10.9
11.0	773.0	411.2	-251.	-160.	0.	15.00	16.41	5.	-0.03787	10.10	5.90	7.00	4.90	12.3
11.0	792.0	424.6	-252.	-173.	0.	16.25	17.51	5.	-0.04056	11.30	5.80	7.40	5.20	13.5
11.0	803.6	431.0	-248.	-183.	0.	17.33	18.42	5.	-0.04276	12.20	5.80	7.30	5.80	14.2

Model Output 03-03-80 **Actuals**





03-04 MARCH 1980



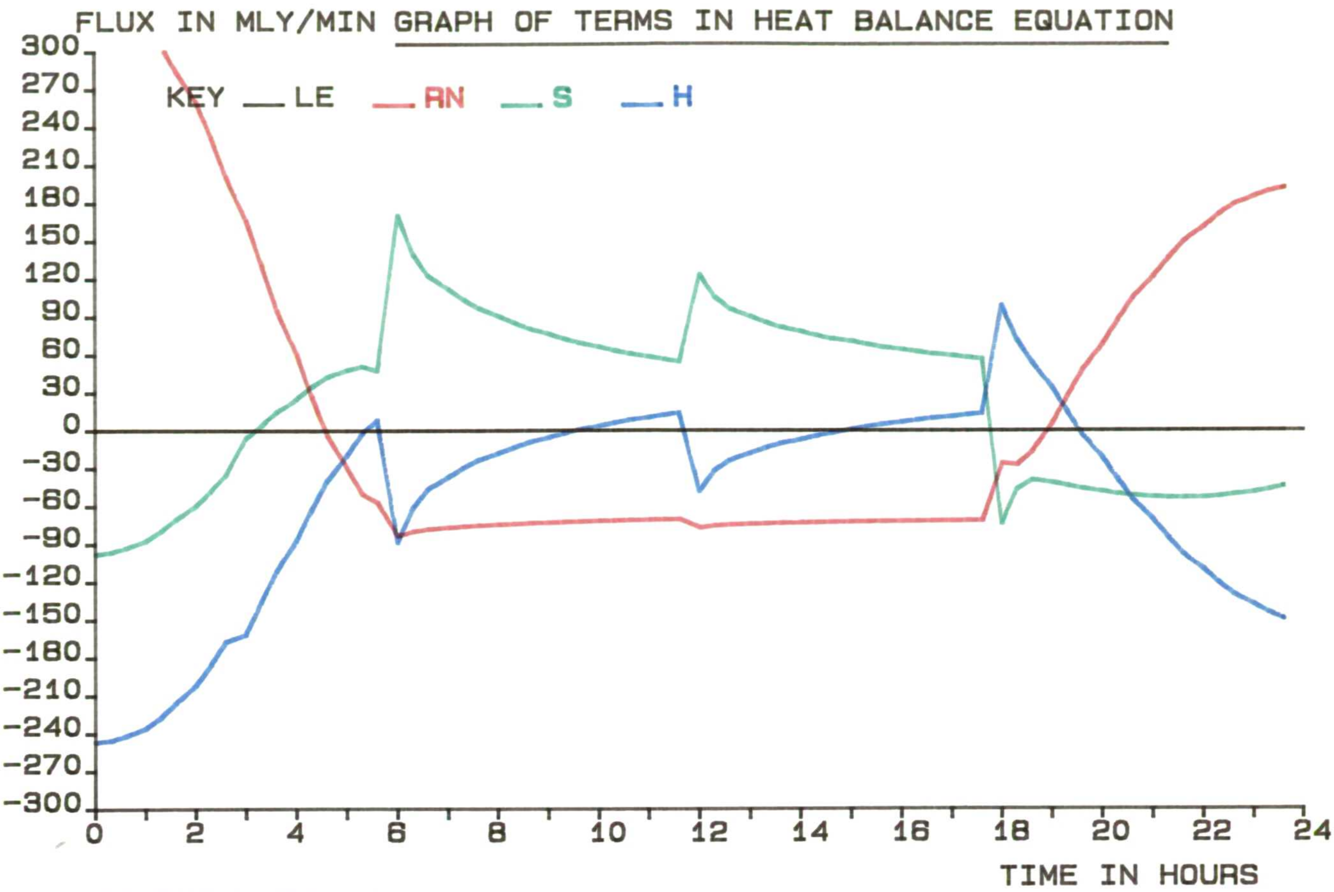
04-03-80

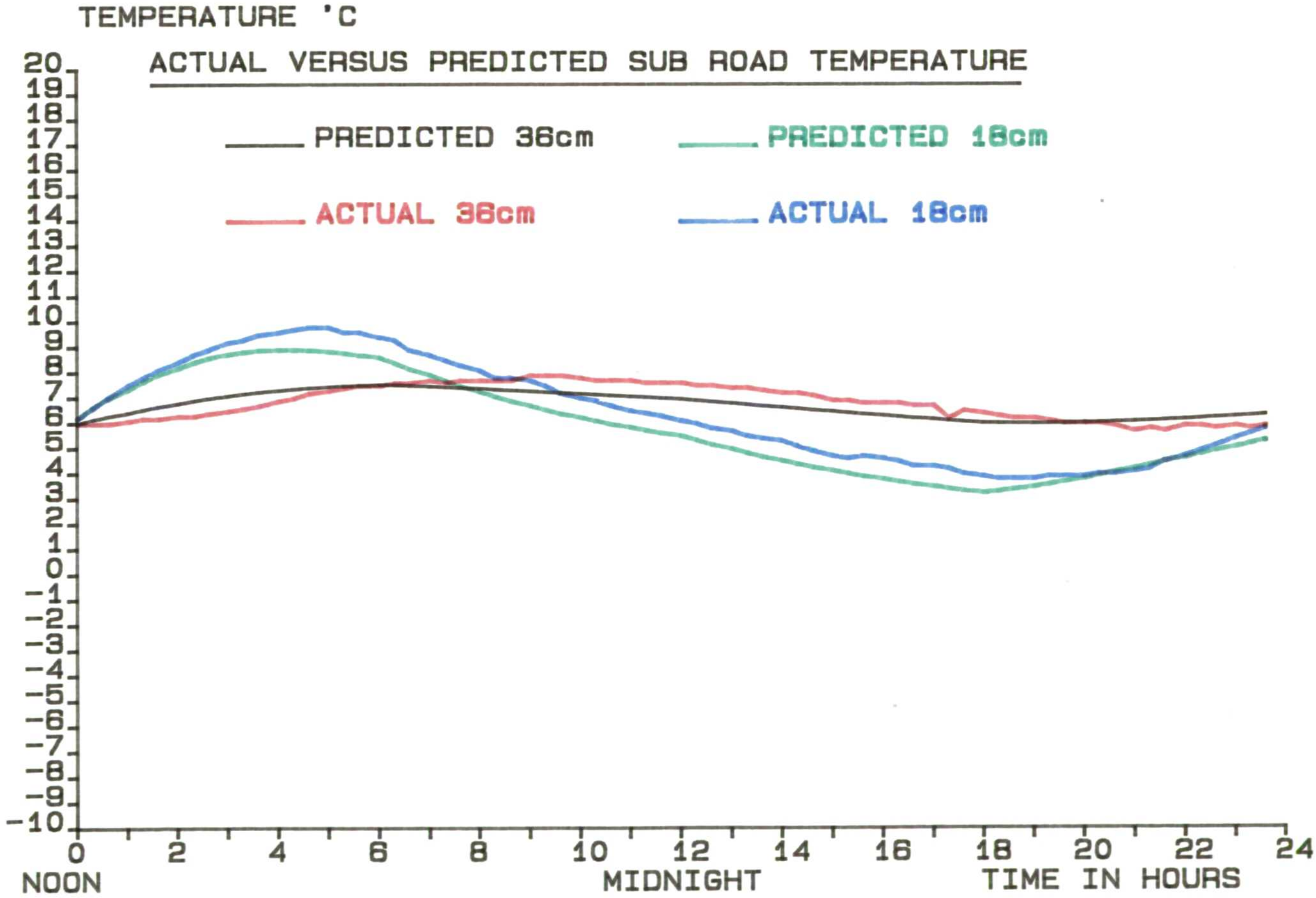
COMPUTED DATA
SAT. VAP. PRESSURE(MB)= 11.24
VAPOUR PRESSURE(MB)= 6.86
REL. HUMIDITY FRACTION = 0.61
APPROX. PRECIP. WATER(MM)= 10.9
ROAD DAMPING DEPTH(CM)= 72.
AIR DAMPING DEPTH(CM)= 2617. 3001.
AIR HEAT TRANSFER COEF.(CGS)= 0.00256 0.00328

DEC	R	T36	T18	TS	UA	D	TIME WET
-5.894	0.992	279.2	279.4	13.1	426. 575.	0.5	0

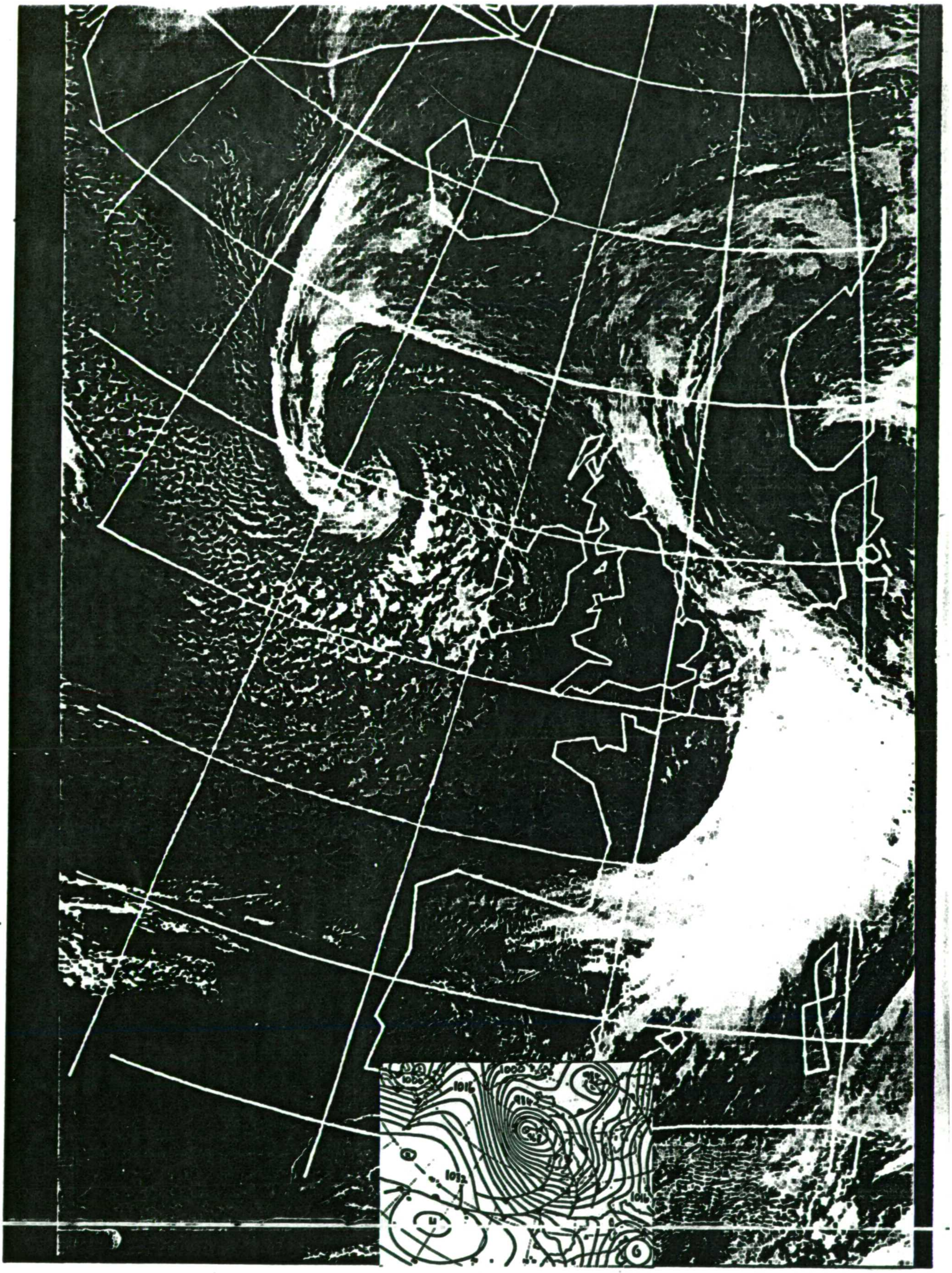
SOLAR TIME	SUN	RN	S (ALL MLY./MIN.)	H	LE	TD	TC (C.)	SUN	K1	TO	T36	Air	T18	Tslab
12.0	707.7	429.7	-116.	-314.	0.	13.10	17.45	1.	-0.00083	13.10	6.00	8.10	6.20	13.10
12.0	704.7	426.5	-115.	-312.	0.	15.25	17.41	0.	-0.00082	13.90	6.00	8.10	6.60	14.80
12.0	695.5	417.1	-110.	-308.	0.	16.27	17.28	0.	-0.00081	14.50	6.00	8.40	7.00	15.60
13.0	680.6	401.8	-103.	-300.	0.	16.67	17.06	0.	-0.00079	15.00	6.10	8.70	7.50	16.10
13.0	659.6	380.3	-93.	-288.	0.	16.71	16.76	0.	-0.00076	15.30	6.20	9.00	7.80	16.70
13.0	632.9	353.2	-80.	-273.	0.	16.53	16.35	0.	-0.00072	15.60	6.20	9.00	8.10	16.80
14.0	601.1	321.3	-67.	-255.	0.	16.20	15.87	0.	-0.00067	15.40	6.30	8.00	8.40	16.70
14.0	563.9	284.7	-51.	-234.	0.	15.74	15.29	0.	-0.00062	15.50	6.30	9.10	8.70	16.80
14.0	521.9	244.3	-35.	-209.	0.	15.19	14.63	0.	-0.00055	15.10	6.40	9.30	8.90	16.50
15.0	478.7	199.8	-3.	-198.	0.	14.35	13.51	0.	-0.00053	14.80	6.50	8.70	9.20	15.90
15.0	428.2	155.1	10.	-166.	0.	13.50	12.66	0.	-0.00044	14.50	6.60	8.90	9.30	15.80
15.0	374.2	109.8	24.	-135.	0.	12.66	11.81	0.	-0.00036	14.10	6.70	8.60	9.50	15.00
16.0	317.5	65.7	37.	-104.	0.	11.82	10.97	0.	-0.00028	13.50	6.90	8.60	9.60	14.20
16.0	257.8	24.4	49.	-74.	0.	10.99	10.17	0.	-0.00020	12.60	7.00	8.10	9.70	13.10
16.0	195.8	-12.2	58.	-46.	0.	10.20	9.41	0.	-0.00012	11.90	7.20	7.10	9.80	11.90
17.0	130.9	-42.0	63.	-22.	0.	9.48	8.76	0.	-0.00006	10.90	7.30	7.40	9.80	10.80
17.0	53.7	-63.9	65.	-2.	0.	8.85	8.21	0.	-0.00001	10.80	7.40	7.00	9.60	9.80
17.0	0.0	-70.5	60.	10.	0.	8.37	7.89	0.	0.00003	10.30	7.50	6.40	9.60	8.90
18.0	0.0	-67.9	167.	-99.	0.	6.66	4.96	0.	-0.00027	8.40	7.50	5.30	9.40	7.90
18.0	0.0	-65.2	138.	-74.	0.	5.46	4.26	0.	-0.00020	7.70	7.60	5.00	9.30	7.30
18.0	0.0	-63.8	122.	-59.	0.	4.67	3.87	0.	-0.00016	7.10	7.60	4.30	8.90	6.60
19.0	0.0	-62.8	112.	-50.	0.	4.14	3.61	0.	-0.00014	6.40	7.70	4.30	8.70	5.80
19.0	0.0	-62.0	104.	-42.	0.	3.78	3.41	0.	-0.00012	6.10	7.60	3.90	8.50	5.50
19.0	0.0	-61.4	97.	-36.	0.	3.51	3.24	0.	-0.00010	5.60	7.70	2.50	8.30	4.80
20.0	0.0	-60.8	91.	-31.	0.	3.30	3.10	0.	-0.00008	5.20	7.70	2.30	8.10	4.60
20.0	0.0	-60.3	86.	-26.	0.	3.13	2.97	0.	-0.00007	4.80	7.70	1.90	7.80	4.20
20.0	0.0	-59.9	81.	-22.	0.	2.99	2.85	0.	-0.00006	4.50	7.70	2.20	7.80	3.90
21.0	0.0	-59.5	77.	-18.	0.	2.87	2.75	0.	-0.00005	4.40	7.90	1.70	7.70	3.70
21.0	0.0	-59.2	73.	-14.	0.	2.76	2.65	0.	-0.00004	4.20	7.90	1.80	7.50	3.40
21.0	0.0	-58.8	69.	-11.	0.	2.67	2.57	0.	-0.00003	4.00	7.90	1.40	7.20	3.20
22.0	0.0	-58.6	66.	-8.	0.	2.58	2.49	0.	-0.00002	3.60	7.50	0.80	7.00	2.80
22.0	0.0	-56.3	63.	-6.	0.	2.50	2.42	0.	-0.00002	3.30	7.70	-0.20	6.90	2.40
22.0	0.0	-58.1	61.	-4.	0.	2.43	2.36	0.	-0.00001	3.00	7.70	-0.60	6.70	2.20
23.0	0.0	-57.8	58.	-1.	0.	2.36	2.30	0.	0.00000	2.80	7.70	-0.20	6.50	1.90
23.0	0.0	-57.6	56.	1.	0.	2.31	2.25	0.	0.00000	2.50	7.60	-0.10	6.40	1.70
23.0	0.0	-57.4	54.	2.	0.	2.25	2.20	0.	0.00001	2.40	7.60	-0.60	6.30	1.50
0.0	0.0	-62.8	124.	-62.	0.	1.33	0.42	0.	-0.00008	2.30	7.60	-0.30	6.10	1.50
0.0	0.0	-61.5	106.	-45.	0.	0.70	0.06	0.	-0.00006	2.10	7.50	-0.60	6.00	1.30
0.0	0.0	-60.8	97.	-37.	0.	0.29	-0.12	0.	-0.00004	1.90	7.50	-0.90	5.80	1.10
1.0	0.0	-60.4	91.	-31.	0.	0.02	-0.24	0.	-0.00004	1.70	7.30	-1.00	5.70	0.90
1.0	0.0	-60.1	86.	-27.	0.	-0.15	-0.33	0.	-0.00003	1.50	7.40	-1.30	5.50	0.80
1.0	0.0	-59.8	82.	-23.	0.	-0.28	-0.41	0.	-0.00003	1.40	7.30	-1.50	5.40	0.50
2.0	0.0	-59.5	79.	-20.	0.	-0.38	-0.48	0.	-0.00002	1.30	7.20	-1.50	5.30	0.40
2.0	0.0	-59.3	76.	-17.	0.	-0.46	-0.54	0.	-0.00002	1.20	7.20	-0.30	5.10	0.30
2.0	0.0	-59.1	73.	-15.	0.	-0.52	-0.59	0.	-0.00002	1.10	7.10	-1.00	4.90	0.20
3.0	0.0	-58.9	70.	-12.	0.	-0.58	-0.64	0.	-0.00001	0.70	6.90	-1.20	4.70	-0.10
3.0	0.0	-58.8	68.	-10.	0.	-0.63	-0.69	0.	-0.00001	0.70	6.90	-1.60	4.60	-0.20
3.0	0.0	-58.6	66.	-8.	0.	-0.68	-0.73	0.	-0.00001	0.60	6.80	-1.70	4.70	-0.30
4.0	0.0	-58.5	64.	-6.	0.	-0.72	-0.77	0.	-0.00001	0.70	6.80	-1.80	4.60	-0.20
4.0	0.0	-58.4	62.	-5.	0.	-0.76	-0.80	0.	-0.00001	0.50	6.60	-1.50	4.50	-0.30
4.0	0.0	-58.2	60.	-3.	0.	-0.80	-0.83	0.	0.00000	0.40	6.70	-2.20	4.30	-0.50
5.0	0.0	-58.1	59.	-2.	0.	-0.83	-0.86	0.	0.00000	0.50	6.70	-1.90	4.30	-0.40
5.0	0.0	-58.0	58.	0.	0.	-0.86	-0.89	0.	0.00000	0.50	6.20	-1.30	4.20	-0.40
5.0	0.0	-57.9	56.	1.	0.	-0.89	-0.92	0.	0.00000	0.90	6.50	-0.40	4.00	0.10
6.0	0.0	-25.9	-67.	93.	0.	0.57	2.02	0.	0.00011	1.10	6.40	0.00	3.90	0.20
6.0	0.0	-27.0	-42.	68.	0.	1.56	2.56	0.	0.00008	1.20	6.30	0.00	3.80	0.20
6.0	71.5	-16.5	-35.	51.	0.	2.25	2.93	0.	0.00006	1.30	6.20	0.50	3.80	0.30
7.0	134.4	5.7	-38.	31.	0.	2.79	3.34	0.	0.00004	1.60	6.20	0.80	3.60	0.50
7.0	165.6	27.1	-40.	12.	0.	3.26	3.74	0.	0.00002	2.10	6.10	1.00	3.90	1.00
7.0	187.7	48.0	-43.	-6.	0.	3.69	4.12	0.	-0.00001	2.50	6.60	2.00	3.90	1.40
8.0	205.8	68.2	-45.	-23.	0.	4.10	4.50	0.	-0.00003	3.00	6.00	2.50	3.90	2.00
8.0	221.3	87.4	-48.	-41.	0.	4.48	4.86	0.	-0.00005	3.40	6.00	2.70	4.00	2.20
8.0	234.9	105.4	-49.	-57.	0.	4.84	5.20	0.	-0.00007	4.10	5.90	3.30	4.00	3.10
9.0	247.0	122.0	-50.	-72.	0.	5.18	5.53	0.	-0.00009	4.60	5.70	3.80	4.10	3.60
9.0	257.7	136.9	-51.	-86.	0.	5.51	5.83	0.	-0.00010	5.50	5.60	4.70	4.20	5.00
9.0	267.2	150.2	-51.	-99.	0.	5.81	6.11	0.	-0.00012	6.30	5.70	5.20	4.50	5.60
10.0	275.4	161.8	-51.	-111.	0.	6.08	6.36	0.	-0.00013	6.60	[illegible]	[illegible]	[illegible]	6.20
10.0	282.4	171.6	-50.	-122.	0.	6.33	6.58	0.	-0.00015	7.50	5.90	6.20	4.90	7.10
10.0	288.1	179.6	-49.	-131.	0.	6.56	6.78	0.	-0.00016	8.20	5.60	6.00	5.10	8.00
11.0	292.6	185.8	-47.	-139.	0.	6.75	6.95	0.	-0.00017	8.70	5.90	6.00	5.40	8.00
11.0	295.6	190.2	-45.	-146.	0.	6.92	7.08	0.	-0.00017	8.90	5.80	6.80	5.60	8.70
11.0	297.7	192.7	-43.	-151.	0.	7.05	7.19	0.	-0.00018	9.10	5.90	6.80	5.80	9.00

Model Output 04-03-80 **Actuals**





04-05 MARCH 1980



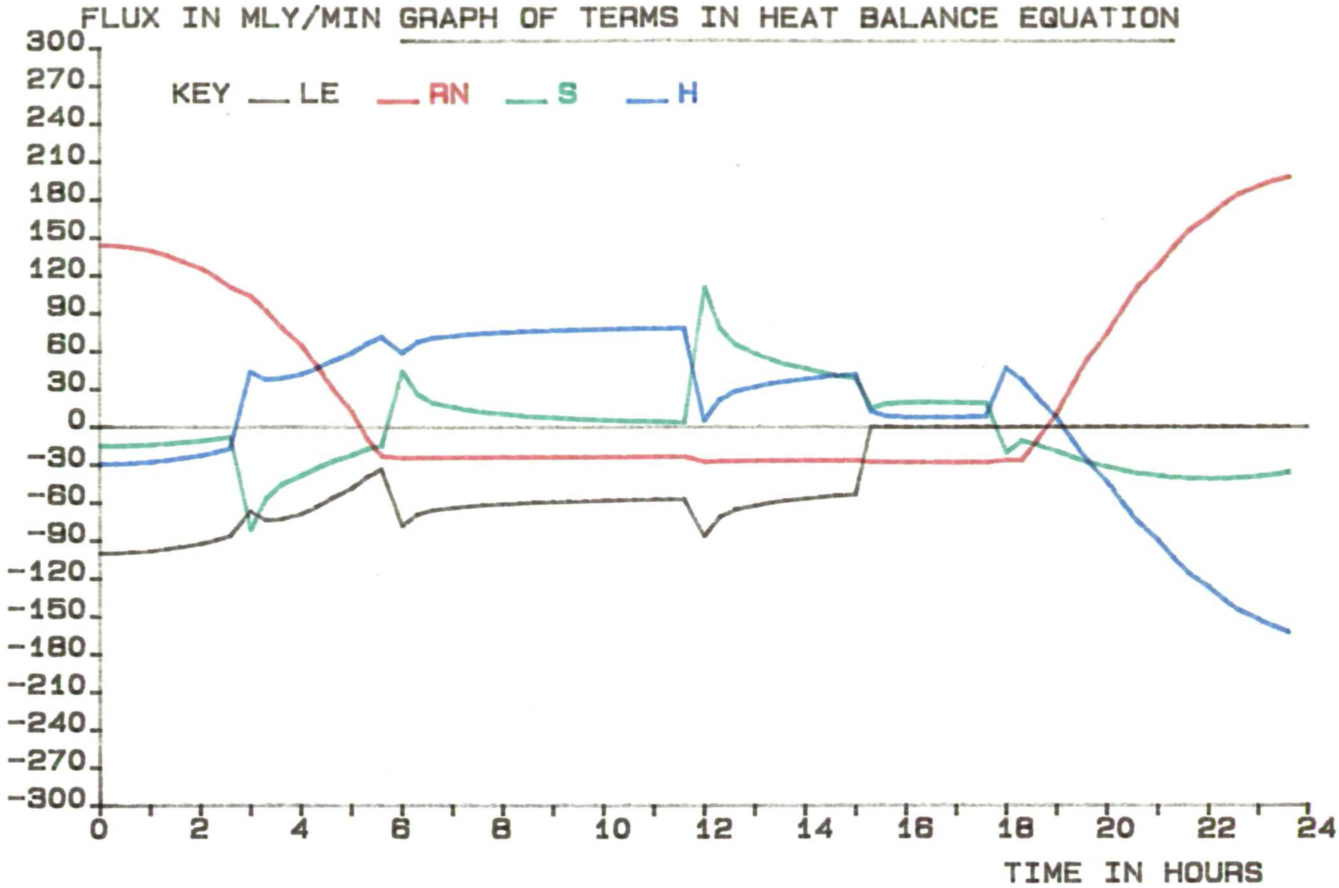
06-03-80

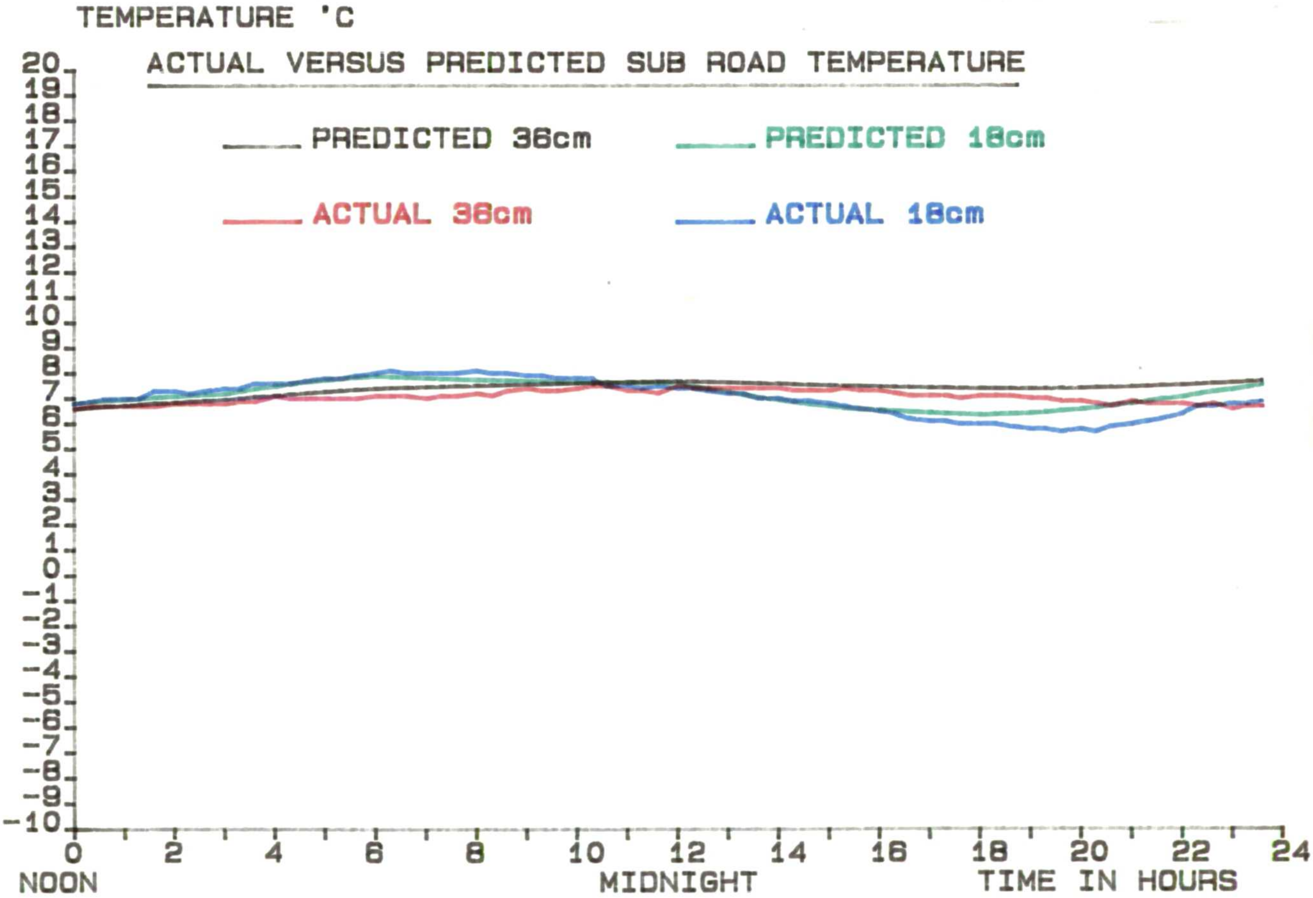
COMPUTED DATA
SAT. VAP. PRESSURE(MB)= 10.29
VAPOUR PRESSURE(MB)= 9.67
REL. HUMIDITY FRACTION = 0.94
APPROX. PRECIP. WATER(MM)= 15.1
ROAD DAMPING DEPTH(CM)= 72.
AIR DAMPING DEPTH(CM)= 3199. 3349.
AIR HEAT TRANSFER COEF.(CGS)= 0.00368 0.00400

DEC	R	T36	T18	TS	UA	D	TIME WET
-5.118	0.993	279.8	280.0	7.7	661. 731.	0.5	12

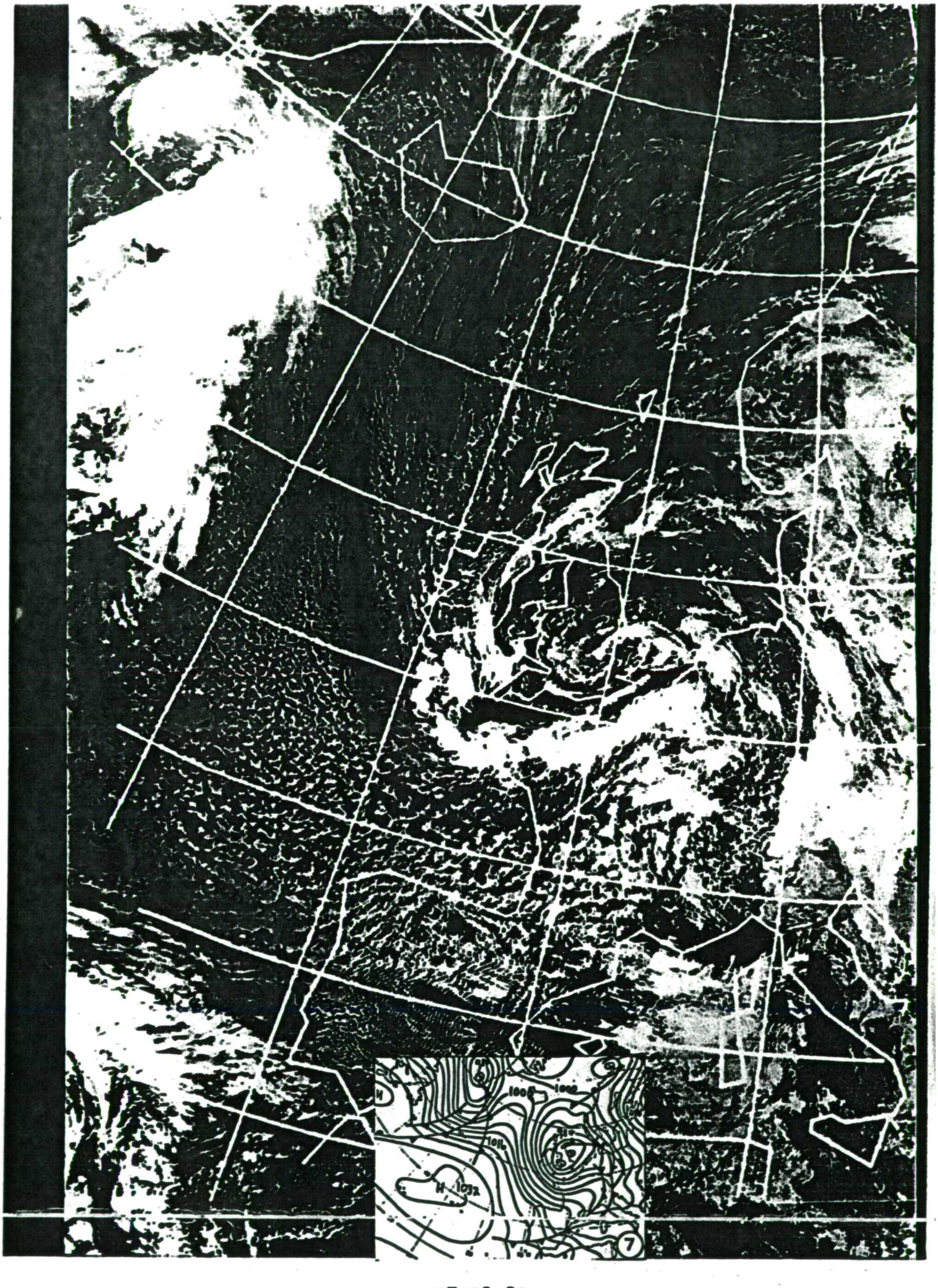
SOLAR TIME	SUN	RN	S (ALL MLY./MIN.)	H	LE	TD	TC (C.)	SUM	RI	~~TO~~	~~T36~~	Air	T18	Tslab
12.0	221.5	144.1	-15.	-29.	-100.	7.70	8.27	-99.	-0.00002	7.70	6.6	6.60	6.80	7.60
12.0	221.3	143.6	-15.	-29.	-99.	7.98	8.27	-99.	-0.00002	7.80	6.7	6.80	6.90	7.60
12.0	220.6	142.1	-15.	-28.	-99.	8.12	8.26	-198.	-0.00002	7.70	6.7	6.80	7.00	7.40
13.0	219.5	139.7	-14.	-28.	-98.	8.18	8.24	-296.	-0.00002	7.80	6.7	6.90	7.00	7.50
13.0	217.9	136.2	-13.	-26.	-96.	8.20	8.22	-393.	-0.00002	7.90	6.7	7.20	7.00	7.60
13.0	215.8	131.6	-12.	-25.	-95.	8.19	8.19	-487.	-0.00002	8.00	6.7	7.50	7.30	7.70
14.0	213.2	125.9	-11.	-23.	-92.	8.17	8.15	-580.	-0.00002	8.10	6.8	7.80	7.30	7.80
14.0	210.0	118.9	-10.	-20.	-89.	8.13	8.10	-669.	-0.00002	8.50	6.8	8.20	7.20	8.00
14.0	206.2	110.5	-8.	-17.	-86.	8.08	8.04	-755.	-0.00001	8.30	6.8	8.60	7.30	8.20
15.0	201.7	103.7	-81.	44.	-66.	8.94	9.79	-821.	0.00004	9.30	6.8	9.40	7.10	9.00
15.0	196.3	92.1	-56.	38.	-74.	9.42	9.90	-895.	0.00003	9.20	6.9	10.10	7.40	9.00
15.0	189.8	79.2	-45.	39.	-73.	9.65	9.88	-967.	0.00003	9.40	6.9	10.10	7.60	9.10
16.0	181.8	64.9	-38.	42.	-69.	9.74	9.82	-1036.	0.00003	9.30	7.1	10.00	7.60	9.20
16.0	171.5	49.0	-33.	47.	-63.	9.74	9.74	-1099.	0.00004	9.00	7.0	10.30	7.60	9.30
16.0	157.2	31.4	-27.	52.	-56.	9.68	9.63	-1155.	0.00004	9.50	7.0	10.60	7.70	9.30
17.0	134.5	12.3	-23.	59.	-48.	9.60	9.51	-1204.	0.00005	9.00	7.0	10.50	7.80	9.20
17.0	84.4	-8.9	-18.	66.	-40.	9.48	9.37	-1243.	0.00005	9.60	7.0	10.60	7.80	9.10
17.0	0.0	-23.2	-15.	72.	-33.	9.38	9.27	-1276.	0.00006	9.60	7.0	10.70	7.90	9.00
18.0	0.0	-24.7	44.	59.	-78.	8.59	7.81	-1354.	0.00005	9.60	7.1	10.70	8.00	8.60
18.0	0.0	-24.4	26.	67.	-69.	8.12	7.65	-1423.	0.00005	9.40	7.1	10.60	8.10	8.90
18.0	0.0	-24.2	19.	71.	-65.	7.85	7.56	-1488.	0.00006	9.40	7.1	10.50	8.00	8.60
19.0	0.0	-24.2	15.	72.	-64.	7.70	7.55	-1552.	0.00006	9.40	7.0	10.40	8.00	8.60
19.0	0.0	-24.1	13.	73.	-62.	7.62	7.53	-1614.	0.00006	9.00	7.1	9.60	8.00	8.50
19.0	0.0	-24.1	11.	74.	-61.	7.57	7.52	-1676.	0.00006	8.40	7.1	9.20	8.00	7.80
20.0	0.0	-24.1	10.	75.	-61.	7.53	7.50	-1737.	0.00006	8.00	7.2	8.90	8.10	7.10
20.0	0.0	-24.0	9.	76.	-60.	7.51	7.49	-1797.	0.00006	7.60	7.1	8.50	8.00	6.80
20.0	0.0	-24.0	8.	76.	-60.	7.50	7.48	-1856.	0.00006	7.50	7.3	8.50	8.00	6.50
21.0	0.0	-24.0	7.	77.	-59.	7.49	7.47	-1916.	0.00006	7.40	7.4	8.30	7.90	6.60
										7.70	7.3	8.30	7.90	7.00
21.0	0.0	-24.0	6.	77.	-59.	7.48	7.47	-1974.	0.00006	7.50	7.3	7.70	7.80	6.80
21.0	0.0	-24.0	5.	77.	-58.	7.47	7.46	-2033.	0.00006	7.20	7.4	7.70	7.60	6.70
22.0	0.0	-24.0	5.	77.	-58.	7.46	7.46	-2091.	0.00006	7.10	7.5	7.90	7.50	6.50
22.0	0.0	-24.0	4.	78.	-58.	7.46	7.45	-2149.	0.00006	6.90	7.5	7.50	7.50	6.20
22.0	0.0	-23.9	4.	78.	-58.	7.45	7.45	-2207.	0.00006	6.50	7.3	7.00	7.50	5.80
23.0	0.0	-23.9	4.	78.	-58.	7.45	7.45	-2264.	0.00006	6.20	7.3	6.50	7.40	5.30
23.0	0.0	-23.9	3.	78.	-57.	7.45	7.44	-2322.	0.00006	6.00	7.2	6.40	7.50	5.30
23.0	0.0	-23.9	3.	78.	-57.	7.44	7.44	-2379.	0.00006	6.10	7.5	6.50	7.40	5.30
0.0	0.0	-28.1	110.	5.	-87.	6.15	4.85	-2465.	0.00000	6.30	7.4	6.90	7.40	5.70
0.0	0.0	-27.5	78.	22.	-72.	5.35	4.56	-2537.	0.00001	6.30	7.4	6.80	7.30	5.80
0.0	0.0	-27.3	65.	28.	-66.	4.90	4.44	-2603.	0.00002	6.30	7.4	6.50	7.20	5.70
1.0	0.0	-27.1	58.	32.	-63.	4.64	4.38	-2665.	0.00002	6.00	7.4	5.00	7.20	5.50
1.0	0.0	-27.0	53.	34.	-60.	4.49	4.34	-2726.	0.00002	5.70	7.4	4.60	7.00	5.10
1.0	0.0	-27.0	49.	36.	-59.	4.40	4.30	-2784.	0.00002	5.50	7.4	4.40	7.00	4.90
2.0	0.0	-26.9	46.	38.	-57.	4.33	4.27	-2841.	0.00002	5.30	7.3	4.40	6.90	4.60
2.0	0.0	-26.8	43.	40.	-56.	4.29	4.25	-2897.	0.00002	5.00	7.3	3.90	6.90	4.40
2.0	0.0	-26.8	41.	41.	-55.	4.26	4.22	-2951.	0.00003	4.90	7.3	4.00	6.80	4.30
3.0	0.0	-26.7	38.	42.	-54.	4.23	4.20	-3005.	0.00003	4.60	7.4	3.70	6.70	3.90
3.0	0.0	-27.8	14.	13.	0.	4.47	4.72	-3005.	0.00001	4.30	7.3	3.40	6.60	3.50
3.0	0.0	-28.0	18.	9.	0.	4.63	4.78	-3005.	0.00001	3.90	7.3	3.40	6.50	3.10
4.0	0.0	-28.0	19.	8.	0.	4.71	4.80	-3005.	0.00000	3.80	7.2	3.60	6.10	3.20
4.0	0.0	-28.0	20.	8.	0.	4.76	4.80	-3005.	0.00000	3.80	7.1	3.90	6.20	3.20
4.0	0.0	-28.0	19.	8.	0.	4.78	4.80	-3005.	0.00000	3.60	7.1	3.60	6.10	2.90
5.0	0.0	-28.0	19.	8.	0.	4.79	4.80	-3005.	0.00000	3.70	7.1	3.80	6.10	2.90
5.0	0.0	-28.0	19.	8.	0.	4.79	4.79	-3005.	0.00001	3.70	7.0	4.30	6.00	3.40
5.0	0.0	-28.0	19.	8.	0.	4.79	4.79	-3005.	0.00001	4.10	7.1	4.40	6.00	3.60
6.0	0.0	-26.3	-20.	47.	0.	5.26	5.72	-3005.	0.00003	4.30	7.1	4.40	6.00	3.60
6.0	0.0	-26.6	-11.	38.	0.	5.57	5.88	-3005.	0.00002	4.10	7.1	4.40	5.90	3.40
6.0	89.4	-11.2	-14.	24.	0.	5.84	6.11	-3005.	0.00002	4.30	7.0	4.70	5.80	3.50
7.0	141.4	11.0	-20.	8.	0.	6.12	6.40	-3005.	0.00000	4.30	7.0	5.10	5.80	3.60
7.0	169.9	32.5	-24.	-9.	0.	6.41	6.69	-3005.	-0.00001					
7.0	190.9	53.4	-28.	-26.	0.	6.70	6.99	-3005.	-0.00002	4.80	6.9	5.50	5.70	4.30
8.0	208.3	73.7	-32.	-43.	0.	6.99	7.28	-3005.	-0.00003	5.10	6.9	5.90	5.80	4.00
8.0	223.3	92.9	-35.	-59.	0.	7.27	7.56	-3005.	-0.00004	5.70	6.8	6.30	5.70	5.20
8.0	236.6	110.8	-37.	-75.	0.	7.55	7.83	-3005.	-0.00005	6.70	6.7	6.80	5.90	6.70
9.0	248.5	127.4	-39.	-89.	0.	7.82	8.08	-3005.	-0.00005	7.00	6.9	6.90	6.00	6.80
9.0	259.1	142.3	-40.	-103.	0.	8.07	8.32	-3005.	-0.00006	7.50	6.8	7.50	6.10	7.60
9.0	268.4	155.6	-41.	-115.	0.	8.30	8.53	-3005.	-0.00007	9.90	[illegible]	7.60	6.20	9.40
10.0	276.5	167.1	-41.	-126.	0.	8.52	8.73	-3005.	-0.00008	10.00	6.8	8.10	6.40	10.00
10.0	283.3	176.9	-41.	-136.	0.	8.71	8.90	-3005.	-0.00008	8.60	6.7	7.70	6.70	8.10
10.0	289.0	184.8	-41.	-145.	0.	8.88	9.05	-3005.	-0.00009	8.20	6.8	7.50	6.70	7.90
11.0	293.4	191.1	-40.	-152.	0.	9.03	9.18	-3005.	-0.00009	7.60	6.6	8.20	6.80	7.20
11.0	296.6	195.4	-38.	-158.	0.	9.15	9.28	-3005.	-0.00010	7.90	6.7	5.70	6.80	8.00
11.0	298.5	198.0	-36.	-163.	0.	9.26	9.36	-3005.	-0.00010	8.40	6.7	6.80	6.90	8.50

Model Output .06-03-80 Actuals





06-07 MARCH 1980



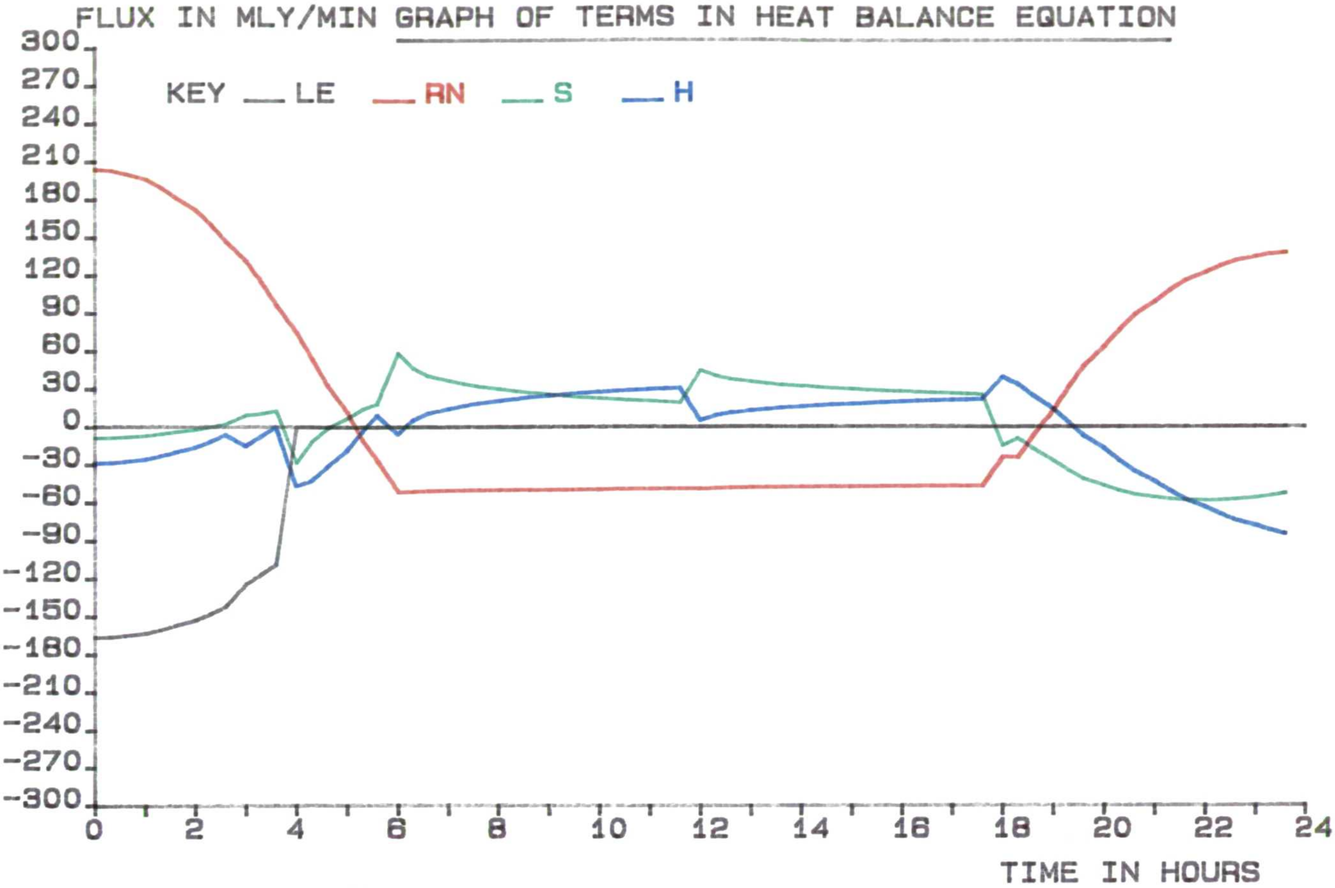
07-03-80

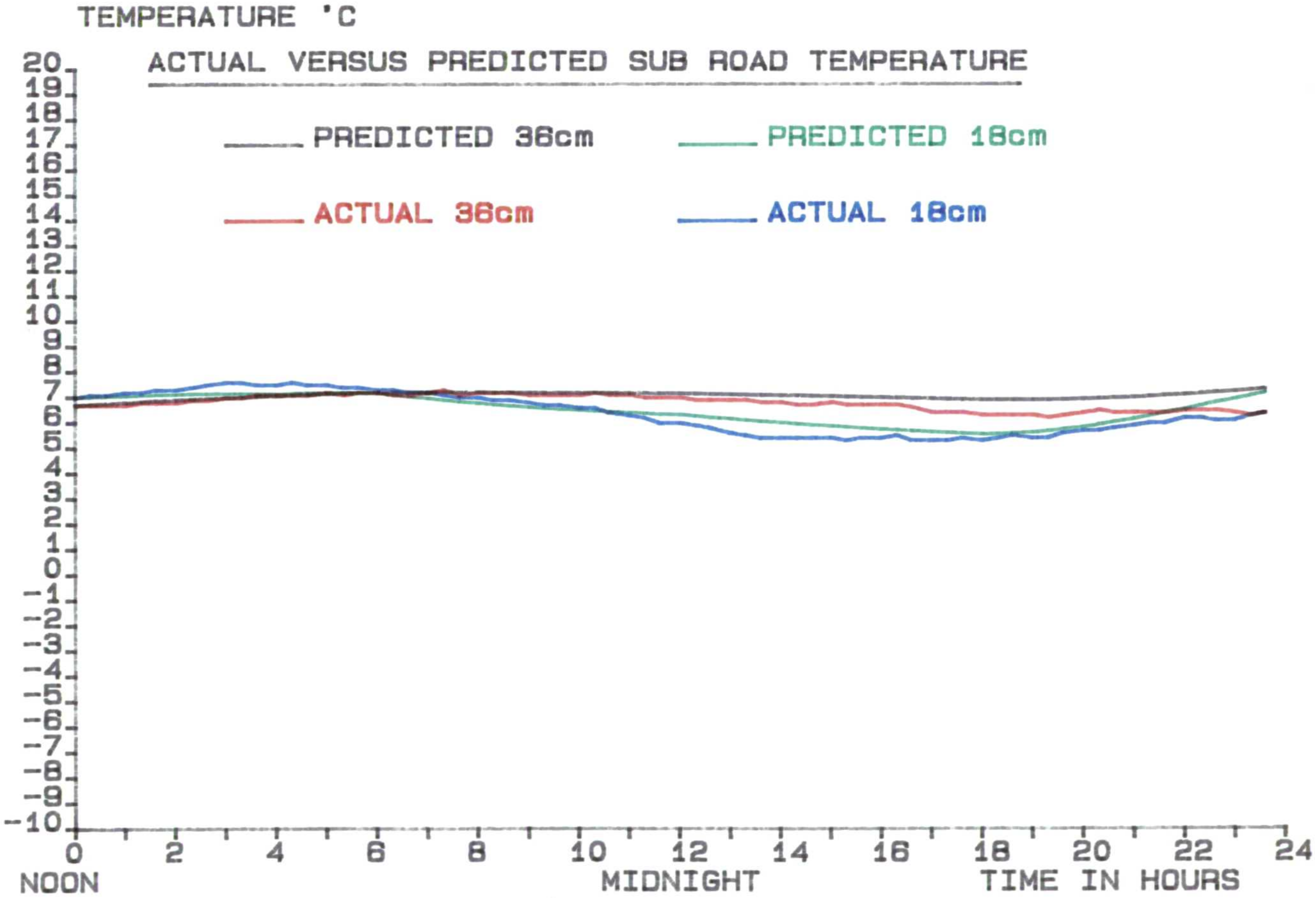
COMPUTED DATA
SAT. VAP. PRESSURE(MB)= 10.01
VAPOUR PRESSURE(MB)= 8.51
REL. HUMIDITY FRACTION = 0.85
APPROX. PRECIP. WATER(MM)= 13.4
ROAD DAMPING DEPTH(CM)= 72.
AIR DAMPING DEPTH(CM)= 3167. 2020.
AIR HEAT TRANSFER COEF.(CGS)= 0.00361 0.00160

DEC	R	T36	T18	TS	UA	D	TIME WET
-4.728	0.993	279.9	280.2	8.2	647. 241.	0.5	12

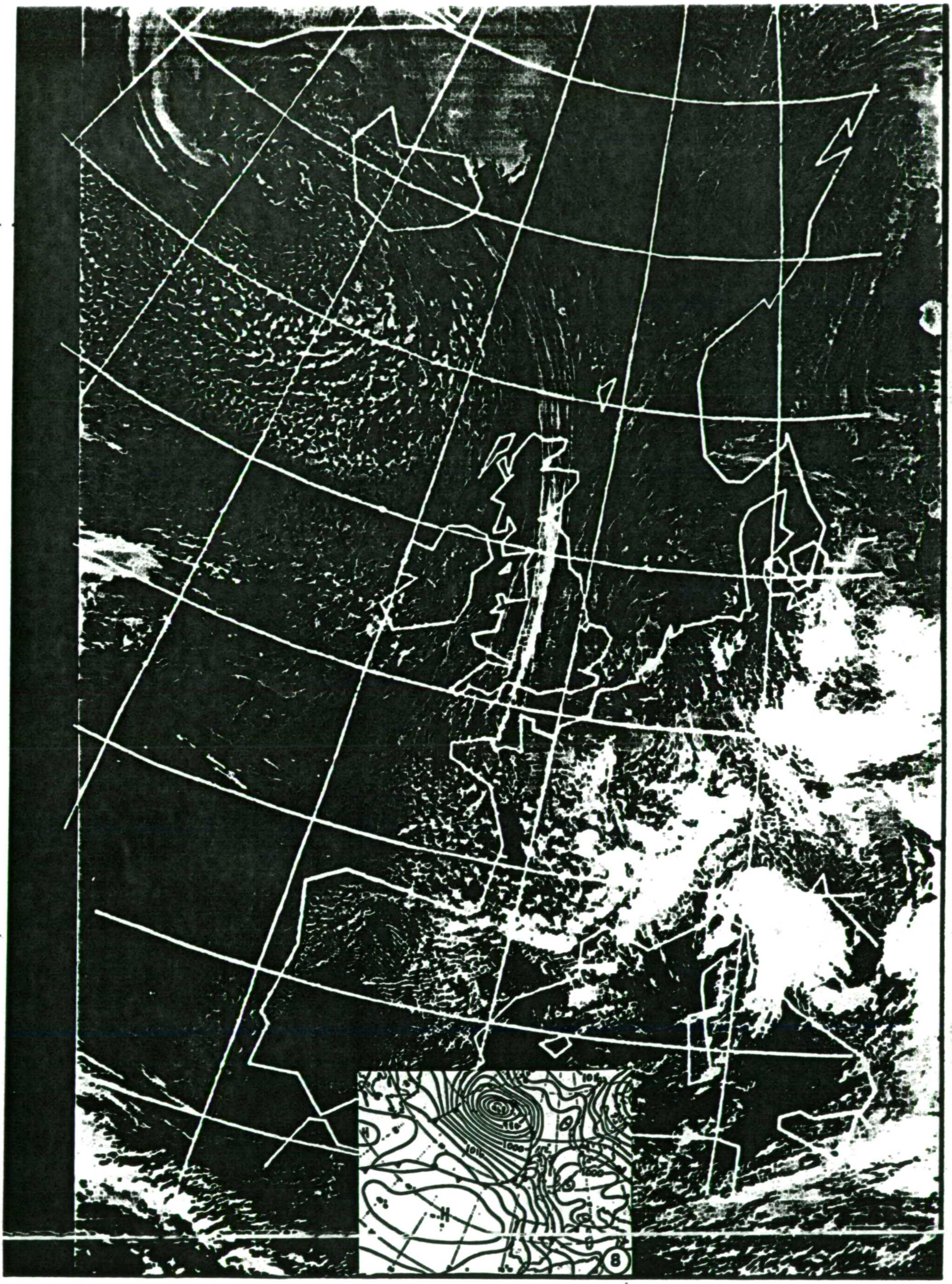
SOLAR TIME	SUN	RN	S (ALL MLY./MIN.)	H	LE	TD	TC (C.)	SUM	RI	TO	T36	Air	T18	Tslab
12.0	298.9	203.9	-9.	-29.	-166.	8.20	7.87	-165.	-0.00002					
12.0	298.2	203.0	-9.	-28.	-166.	8.03	7.86	-166.	-0.00002	8.20	6.7	6.90	7.00	8.20
12.0	296.4	200.3	-8.	-27.	-165.	7.94	7.84	-330.	-0.00002	8.90	6.7	7.60	7.10	9.20
13.0	293.3	195.8	-7.	-26.	-163.	7.87	7.81	-493.	-0.00002	8.20	6.7	6.50	7.10	8.00
13.0	288.9	189.5	-6.	-23.	-160.	7.82	7.77	-654.	-0.00002	8.50	6.7	7.20	7.20	6.00
13.0	283.3	181.4	-4.	-20.	-157.	7.76	7.71	-811.	-0.00002	9.10	6.6	7.00	7.20	9.30
14.0	276.5	171.5	-2.	-16.	-153.	7.70	7.63	-963.	-0.00001	8.60	6.8	6.80	7.30	8.00
14.0	268.4	159.8	0.	-12.	-148.	7.62	7.54	-1111.	-0.00001	8.40	6.8	6.60	7.30	8.50
14.0	259.1	146.4	2.	-6.	-142.	7.53	7.44	-1253.	-0.00001	8.20	6.9	6.90	7.40	8.10
15.0	248.6	130.9	9.	-15.	-125.	7.37	7.21	-1378.	-0.00001	8.40	6.9	7.10	7.50	8.50
15.0	236.8	114.2	11.	-8.	-117.	7.22	7.07	-1495.	-0.00001	8.20	7.0	6.90	7.60	8.10
15.0	223.6	96.0	13.	0.	-109.	7.07	6.92	-1603.	0.00000	7.80	7.0	6.90	7.60	7.70
16.0	208.7	74.4	-28.	-47.	0.	7.44	7.82	-1603.	-0.00004	7.90	7.1	7.00	7.50	7.80
16.0	191.5	53.8	-12.	-43.	0.	7.59	7.74	-1603.	-0.00004	7.90	7.1	6.90	7.50	7.90
16.0	170.7	32.6	-1.	-32.	0.	7.56	7.54	-1603.	-0.00003	7.70	7.1	6.60	7.60	7.50
17.0	142.8	11.2	7.	-19.	0.	7.42	7.28	-1603.	-0.00002	7.40	7.1	6.10	7.50	7.10
17.0	92.9	-10.9	14.	-4.	0.	7.21	6.99	-1603.	0.00000	7.30	7.2	6.30	7.50	7.00
17.0	0.0	-27.3	18.	9.	0.	6.97	6.74	-1603.	0.00001	7.10	7.1	6.50	7.40	6.80
18.0	0.0	-51.9	58.	-6.	0.	6.30	5.63	-1603.	-0.00001	6.80	7.2	6.30	7.40	6.40
18.0	0.0	-51.1	46.	5.	0.	5.86	5.42	-1603.	0.00000	6.50	7.2	5.80	7.30	5.90
18.0	0.0	-50.7	40.	11.	0.	5.59	5.31	-1603.	0.00001	6.40	7.1	5.90	7.30	5.90
19.0	0.0	-50.4	36.	14.	0.	5.42	5.25	-1603.	0.00001	6.40	7.1	6.10	7.20	5.90
19.0	0.0	-50.3	34.	17.	0.	5.31	5.20	-1603.	0.00001	6.20	7.2	6.20	7.20	5.70
19.0	0.0	-50.1	31.	19.	0.	5.23	5.16	-1603.	0.00002	6.10	7.3	6.20	7.10	5.60
20.0	0.0	-50.0	30.	20.	0.	5.18	5.13	-1603.	0.00002	5.80	7.1	6.00	7.00	5.30
20.0	0.0	-49.9	28.	22.	0.	5.14	5.10	-1603.	0.00002	5.90	7.2	5.90	7.00	5.30
20.0	0.0	-49.8	26.	23.	0.	5.10	5.07	-1603.	0.00002	5.90	7.2	5.90	6.90	5.30
21.0	0.0	-49.7	25.	24.	0.	5.07	5.05	-1603.	0.00002	5.70	7.2	5.70	6.90	4.80
										5.50	7.1	5.70	6.80	4.70
21.0	0.0	-49.6	24.	26.	0.	5.05	5.03	-1603.	0.00002	5.10	7.1	5.00	6.70	4.00
21.0	0.0	-49.5	23.	27.	0.	5.03	5.01	-1603.	0.00002	4.80	7.1	4.50	6.70	3.60
22.0	0.0	-49.4	22.	27.	0.	5.01	4.99	-1603.	0.00002	4.50	7.1	4.50	6.60	3.40
22.0	0.0	-49.4	21.	28.	0.	4.99	4.98	-1603.	0.00002	4.40	7.2	4.40	6.60	3.30
22.0	0.0	-49.3	20.	29.	0.	4.98	4.96	-1603.	0.00002	4.10	7.1	4.20	6.40	3.00
23.0	0.0	-49.3	20.	29.	0.	4.96	4.95	-1603.	0.00003	3.90	7.1	4.00	6.30	2.70
23.0	0.0	-49.2	19.	30.	0.	4.95	4.94	-1603.	0.00003	3.70	7.0	3.90	6.20	2.60
23.0	0.0	-49.2	19.	31.	0.	4.94	4.93	-1603.	0.00003	3.60	7.0	3.70	6.00	2.40
0.0	0.0	-49.5	44.	5.	0.	4.61	4.28	-1603.	0.00007	3.40	7.0	3.60	6.00	2.20
0.0	0.0	-48.8	40.	9.	0.	4.36	4.11	-1603.	0.00012	3.20	6.9	3.30	5.90	2.10
0.0	0.0	-48.4	37.	11.	0.	4.19	4.02	-1603.	0.00014	3.10	6.9	3.10	5.80	1.90
1.0	0.0	-48.2	35.	13.	0.	4.07	3.95	-1603.	0.00016	3.00	6.9	3.20	5.60	1.80
1.0	0.0	-48.0	34.	14.	0.	3.99	3.90	-1603.	0.00018	3.00	6.9	3.30	5.50	1.90
1.0	0.0	-47.8	33.	15.	0.	3.92	3.86	-1603.	0.00019	3.00	6.8	3.00	5.40	1.90
2.0	0.0	-47.7	32.	16.	0.	3.87	3.82	-1603.	0.00020	3.00	6.8	3.50	5.40	1.90
2.0	0.0	-47.6	31.	17.	0.	3.83	3.79	-1603.	0.00021	3.40	6.7	4.10	5.40	2.60
2.0	0.0	-47.4	30.	17.	0.	3.79	3.75	-1603.	0.00022	3.70	6.7	4.30	5.40	2.80
3.0	0.0	-47.3	29.	18.	0.	3.76	3.73	-1603.	0.00023	4.10	6.8	5.00	5.40	3.30
3.0	0.0	-47.2	29.	19.	0.	3.73	3.70	-1603.	0.00024	4.30	6.7	5.00	5.30	3.60
3.0	0.0	-47.1	28.	19.	0.	3.70	3.68	-1603.	0.00025	4.40	6.7	5.00	5.40	3.60
4.0	0.0	-47.1	27.	20.	0.	3.68	3.65	-1603.	0.00025	4.40	6.7	5.10	5.40	3.70
4.0	0.0	-47.0	27.	20.	0.	3.65	3.63	-1603.	0.00026	4.60	6.7	5.20	5.50	3.90
4.0	0.0	-46.9	26.	21.	0.	3.63	3.61	-1603.	0.00027	4.70	6.6	5.50	5.30	4.00
5.0	0.0	-46.8	26.	21.	0.	3.61	3.59	-1603.	0.00027	4.50	6.4	5.20	5.30	3.90
5.0	0.0	-46.8	25.	21.	0.	3.60	3.58	-1603.	0.00026	4.60	6.4	5.40	5.30	4.00
5.0	0.0	-46.7	25.	22.	0.	3.58	3.56	-1603.	0.00028	4.60	6.4	5.40	5.40	4.00
6.0	0.0	-23.9	-15.	39.	0.	4.04	4.51	-1603.	0.00050	4.70	6.3	5.40	5.30	4.00
6.0	0.0	-24.4	-9.	34.	0.	4.39	4.74	-1603.	0.00043	4.70	6.3	5.20	5.40	3.80
6.0	95.9	-7.2	-18.	25.	0.	4.76	5.13	-1603.	0.00032	4.80	6.3	5.30	5.50	4.10
7.0	139.0	13.1	-27.	14.	0.	5.17	5.59	-1603.	0.00016	4.90	6.3	5.30	5.40	3.80
7.0	159.9	31.4	-35.	4.	0.	5.61	6.05	-1603.	0.00005	5.30	6.2	5.90	5.40	4.50
7.0	173.4	48.0	-42.	-7.	0.	6.06	6.51	-1603.	-0.00009	5.40	6.3	5.60	5.60	4.50
8.0	183.3	63.1	-47.	-17.	0.	6.50	6.94	-1603.	-0.00022	4.80	6.4	6.10	5.70	5.00
8.0	191.1	76.6	-51.	-26.	0.	6.92	7.35	-1603.	-0.00034	6.40	6.5	6.30	5.70	5.80
8.0	197.4	88.5	-54.	-35.	0.	7.32	7.73	-1603.	-0.00045	6.00	6.4	6.20	5.80	5.40
9.0	202.7	99.0	-56.	-43.	0.	7.70	8.08	-1603.	-0.00055	6.50	6.4	6.10	5.90	5.70
9.0	207.2	108.0	-58.	-51.	0.	8.05	8.40	-1603.	-0.00065	6.70	6.4	6.10	6.00	5.90
9.0	210.9	115.7	-59.	-58.	0.	8.37	8.69	-1603.	-0.00073	[illegible]	[illegible]	[illegible]	[illegible]	5.90
10.0	214.1	122.1	-59.	[illegible]	0.	[illegible]	8.96	-1603.	-0.00081	6.80	6.5	6.10	6.20	6.00
10.0	216.7	127.4	-59.	-69.	0.	8.93	9.20	-1603.	-0.00088	6.40	6.5	6.00	6.20	5.70
10.0	218.7	131.5	-58.	-74.	0.	9.17	9.41	-1603.	-0.00094	7.10	6.5	6.10	6.10	6.30
11.0	220.3	134.6	-57.	-79.	0.	9.38	9.59	-1603.	-0.00100	8.20	6.4	6.60	6.10	7.80
11.0	221.4	136.7	-55.	-82.	0.	9.57	9.75	-1603.	-0.00104	7.70	6.3	6.30	6.30	6.80
11.0	222.1	137.9	-53.	-85.	0.	9.72	9.88	-1603.	-0.00106	7.70	6.4	6.40	6.40	6.90

Model Output 07-03-80 **Actuals**





07-08 MARCH 1980



08-03-80

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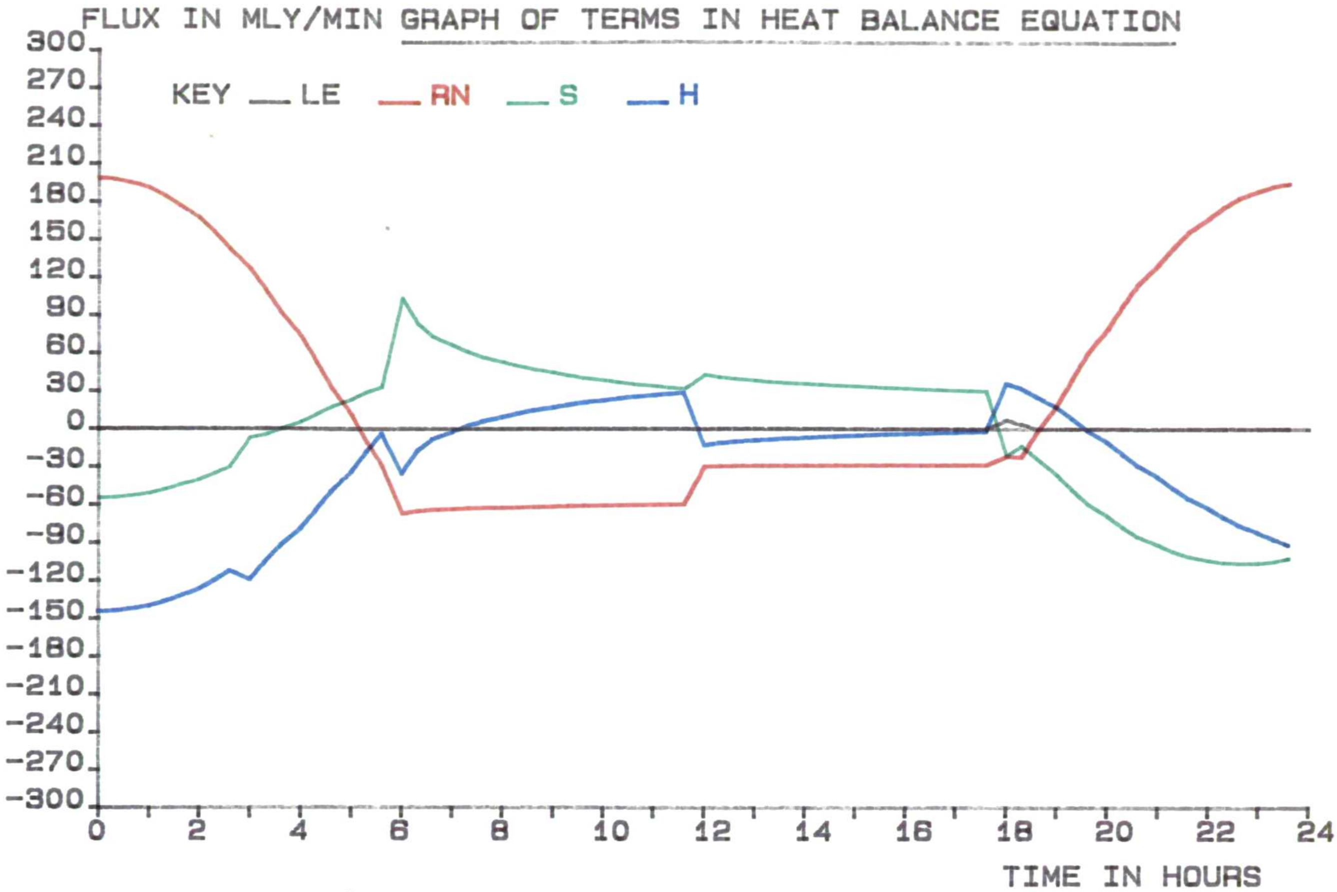
***COMPUTED DATA***
SAT. VAP. PRESSURE(MB)= 10.79
VAPOUR    PRESSURE(MB)=  7.77
REL. HUMIDITY FRACTION =  0.72
APPROX. PRECIP. WATER(MM)=  12.3
ROAD DAMPING DEPTH(CM)=      72.
AIR DAMPING DEPTH(CM)=      2813.       1533.
AIR HEAT TRANSFER COEF.(CGS)=    0.00291     0.00098
```

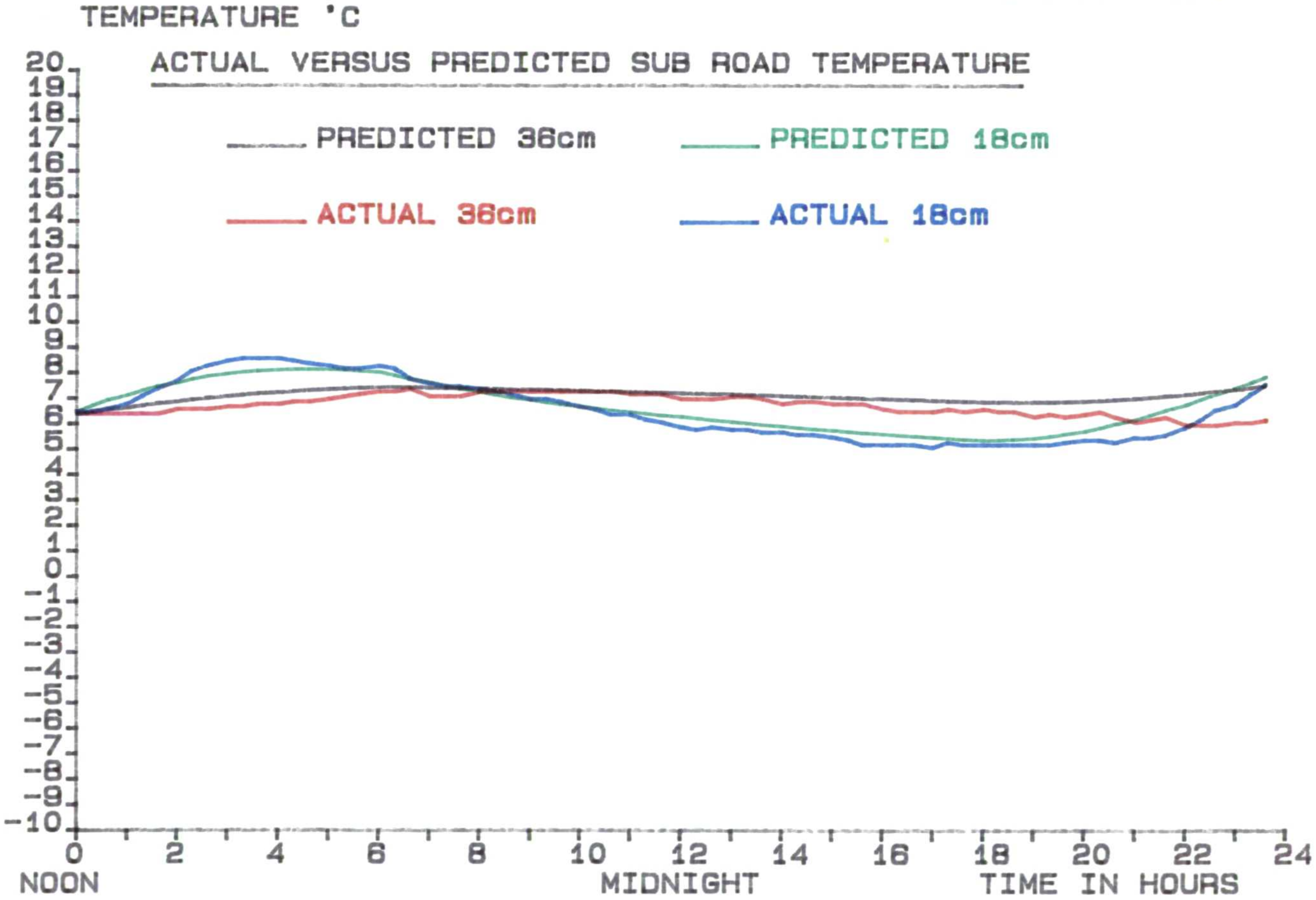
DEC	R	T36	T18	TS	UA	D	TIME WET
-4.337	0.993	279.6	279.7	7.6	499. 131.	0.5	0

SOLAR TIME	SUN	RN	S	H	LE	TD	TC (C.)	SUM	RI
		(ALL MLY./MIN.)							
12.0	301.0	198.5	-55.	-144.	0.	7.60	11.82	1.	-0.00025
12.0	300.3	197.6	-54.	-144.	0.	9.70	11.80	0.	-0.00025
12.0	298.4	195.0	-53.	-142.	0.	10.74	11.77	0.	-0.00025
13.0	295.4	190.6	-51.	-140.	0.	11.23	11.71	0.	-0.00024
13.0	291.0	184.4	-48.	-137.	0.	11.43	11.64	0.	-0.00024
13.0	285.3	176.3	-45.	-132.	0.	11.48	11.53	0.	-0.00023
14.0	278.5	166.6	-40.	-127.	0.	11.44	11.40	0.	-0.00022
14.0	270.5	155.1	-35.	-120.	0.	11.34	11.24	0.	-0.00021
14.0	261.2	141.8	-30.	-112.	0.	11.20	11.05	0.	-0.00019
15.0	251.0	126.1	-7.	-119.	0.	10.81	10.42	0.	-0.00021
15.0	239.1	109.8	-5.	-106.	0.	10.45	10.10	0.	-0.00018
15.0	225.9	91.9	0.	-92.	0.	10.12	9.78	0.	-0.00016
16.0	211.0	72.9	5.	-79.	0.	9.79	9.46	0.	-0.00014
16.0	193.9	52.8	11.	-65.	0.	9.46	9.12	0.	-0.00011
16.0	173.4	31.9	17.	-50.	0.	9.11	8.77	0.	-0.00009
17.0	146.4	10.6	23.	-34.	0.	8.76	8.40	0.	-0.00006
17.0	100.1	-11.3	29.	-18.	0.	8.39	8.02	0.	-0.00003
17.0	0.0	-29.8	33.	-4.	0.	8.03	7.67	0.	-0.00001
18.0	0.0	-67.2	103.	-36.	0.	6.88	5.73	0.	-0.00006
18.0	0.0	-65.1	83.	-18.	0.	6.09	5.30	0.	-0.00003
18.0	0.0	-64.1	72.	-8.	0.	5.59	5.08	0.	-0.00001
19.0	0.0	-63.4	66.	-2.	0.	5.26	4.94	0.	0.00000
19.0	0.0	-62.9	61.	2.	0.	5.05	4.83	0.	0.00000
19.0	0.0	-62.4	56.	6.	0.	4.89	4.74	0.	0.00001
20.0	0.0	-62.1	53.	9.	0.	4.78	4.66	0.	0.00002
20.0	0.0	-61.7	50.	12.	0.	4.68	4.59	0.	0.00002
20.0	0.0	-61.4	47.	15.	0.	4.61	4.53	0.	0.00003
21.0	0.0	-61.2	44.	17.	0.	4.54	4.48	0.	0.00003
21.0	0.0	-60.9	42.	19.	0.	4.49	4.43	0.	0.00003
21.0	0.0	-60.7	40.	21.	0.	4.44	4.39	0.	0.00004
22.0	0.0	-60.6	38.	22.	0.	4.39	4.35	0.	0.00004
22.0	0.0	-60.4	36.	24.	0.	4.35	4.31	0.	0.00004
22.0	0.0	-60.2	35.	25.	0.	4.31	4.28	0.	0.00004
23.0	0.0	-60.1	34.	27.	0.	4.28	4.25	0.	0.00005
23.0	0.0	-60.0	32.	28.	0.	4.25	4.22	0.	0.00005
23.0	0.0	-59.9	31.	29.	0.	4.22	4.20	0.	0.00005
0.0	0.0	-30.0	43.	-13.	0.	4.05	3.87	0.	-0.00088
0.0	0.0	-29.8	41.	-11.	0.	3.90	3.75	0.	-0.00076
0.0	0.0	-29.6	39.	-10.	0.	3.79	3.67	0.	-0.00068
1.0	0.0	-29.4	38.	-9.	0.	3.69	3.60	0.	-0.00062
1.0	0.0	-29.3	37.	-8.	0.	3.62	3.55	0.	-0.00057
1.0	0.0	-29.2	36.	-8.	0.	3.56	3.50	0.	-0.00052
2.0	0.0	-29.1	36.	-7.	0.	3.50	3.45	0.	-0.00047
2.0	0.0	-29.0	35.	-6.	0.	3.45	3.40	0.	-0.00043
2.0	0.0	-28.9	34.	-6.	0.	3.41	3.36	0.	-0.00039
3.0	0.0	-28.9	34.	-5.	0.	3.37	3.32	0.	-0.00035
3.0	0.0	-28.8	33.	-5.	0.	3.33	3.29	0.	-0.00032
3.0	0.0	-28.7	32.	-4.	0.	3.29	3.25	0.	-0.00029
4.0	0.0	-28.6	32.	-4.	0.	3.25	3.22	0.	-0.00025
4.0	0.0	-28.6	31.	-3.	0.	3.22	3.19	0.	-0.00023
4.0	0.0	-28.5	31.	-3.	0.	3.19	3.16	0.	-0.00020
5.0	0.0	-28.5	30.	-3.	0.	3.16	3.13	0.	-0.00017
5.0	0.0	-28.4	30.	-2.	0.	3.13	3.11	0.	-0.00015
5.0	0.0	-28.4	30.	-2.	0.	3.11	3.08	0.	-0.00012
6.0	0.0	-21.8	-21.	36.	7.	3.69	4.28	7.	0.00244
6.0	0.0	-22.4	-14.	32.	4.	4.13	4.56	11.	0.00217
6.0	103.5	-2.9	-23.	25.	0.	4.58	5.04	11.	0.00172
7.0	148.0	18.5	-36.	17.	0.	5.11	5.63	11.	0.00115
7.0	174.4	39.3	-48.	8.	0.	5.69	6.27	11.	0.00055
7.0	194.5	59.5	-59.	-1.	0.	6.31	6.92	11.	-0.00007
8.0	211.5	78.9	-69.	-10.	0.	6.95	7.59	11.	-0.00070
8.0	226.2	97.2	-78.	-20.	0.	7.60	8.25	11.	-0.00132
8.0	239.3	114.2	-86.	-29.	0.	8.25	8.90	11.	-0.00193
9.0	251.1	129.9	-92.	-38.	0.	8.89	9.53	11.	-0.00252
9.0	261.6	143.9	-97.	-47.	0.	9.51	10.14	11.	[illegible]
9.0	272.0	[illegible]	-101.	-55.	0.	10.11	10.70	11.	-0.00361
10.0	278.9	167.0	-104.	-63.	0.	10.67	11.24	11.	-0.00411
10.0	285.7	175.9	-106.	-70.	0.	11.20	11.73	11.	-0.00456
10.0	291.3	183.1	-107.	-77.	0.	11.68	12.17	11.	-0.00497
11.0	295.7	188.6	-106.	-82.	0.	12.13	12.57	11.	-0.00534
11.0	298.8	192.4	-105.	-88.	0.	12.52	12.91	11.	-0.00566
11.0	300.7	194.4	-103.	-92.	0.	12.86	13.21	11.	-0.00593

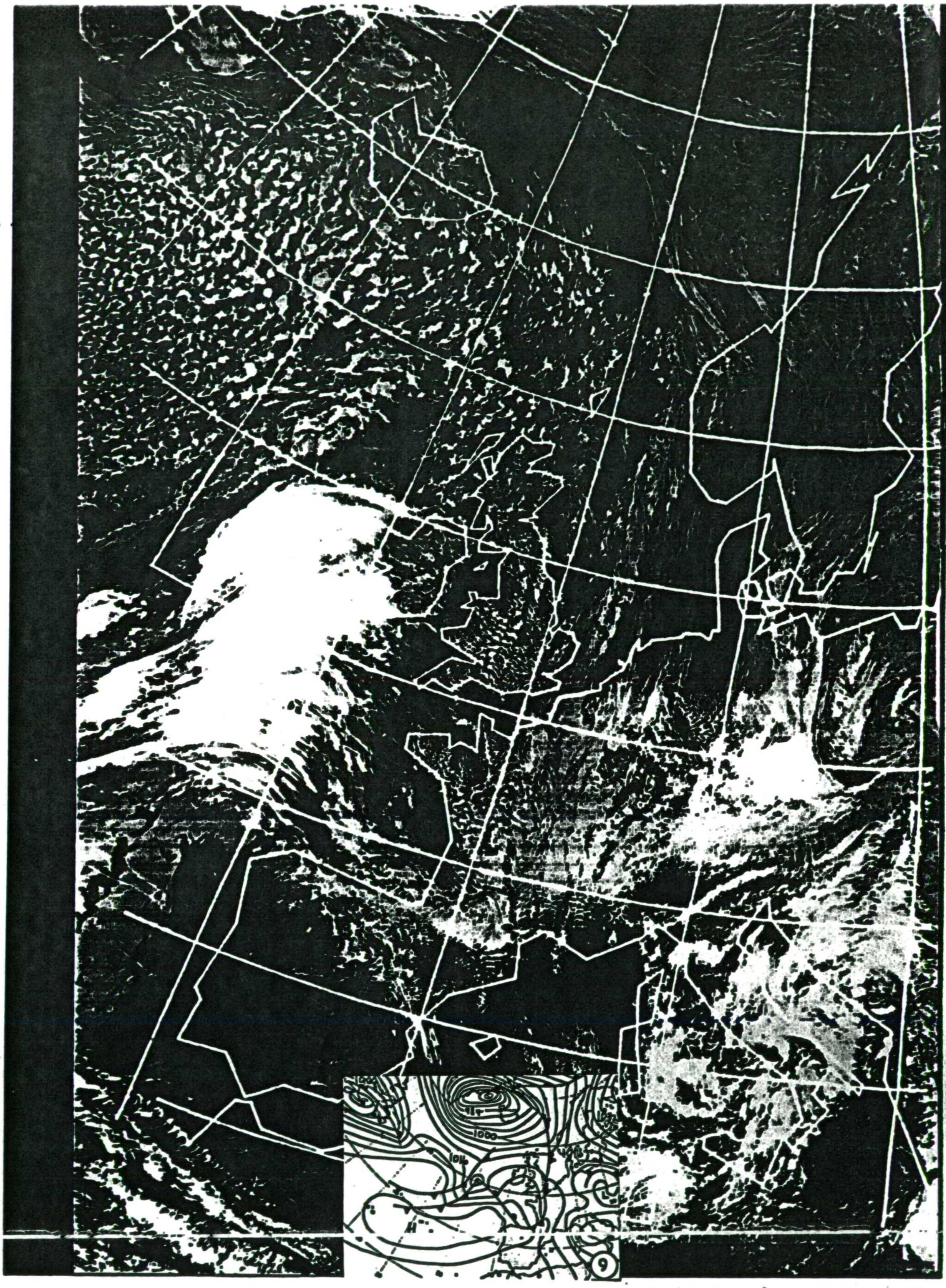
TA	T36	Air	T18	Tslab
7.60	6.4	6.40	6.50	6.60
8.90	6.4	6.90	6.50	8.60
11.40	6.4	7.90	6.60	11.90
11.60	6.4	7.90	6.80	11.40
11.80	6.4	8.10	7.10	11.50
13.50	6.4	9.20	7.40	14.10
13.60	6.6	8.90	7.70	13.50
13.70	6.6	8.80	6.10	13.30
12.10	6.6	8.50	6.30	11.20
11.40	6.7	8.40	6.50	10.50
10.40	6.7	7.80	6.60	9.40
10.10	6.8	7.40	6.60	9.20
9.90	6.8	7.40	6.60	9.90
9.90	6.9	7.50	6.50	9.20
9.40	6.9	7.30	6.40	6.50
8.70	7.0	7.00	6.30	6.60
8.00	7.1	6.70	6.20	7.00
7.60	7.2	6.40	6.20	6.50
7.30	7.3	6.20	6.30	6.00
6.90	7.3	6.10	6.20	5.50
6.50	7.4	6.10	7.80	5.20
5.90	7.1	5.60	7.60	4.50
5.60	7.1	5.00	7.50	4.20
5.40	7.1	5.00	7.50	4.00
5.40	7.3	5.10	7.40	4.00
5.20	7.3	5.00	7.30	3.70
5.00	7.3	5.10	7.20	3.50
4.90	7.3	4.90	7.00	3.40
4.70	7.3	4.20	7.00	3.20
4.50	7.3	4.20	6.90	3.00
4.40	7.3	4.20	6.70	2.80
4.10	7.3	3.90	6.60	2.60
4.00	7.3	3.60	6.40	2.40
3.70	7.2	2.70	6.40	2.30
3.40	7.2	2.20	6.20	2.00
3.30	7.2	2.80	6.10	1.60
3.10	7.0	2.50	5.90	1.60
3.10	7.0	2.50	5.80	1.60
3.30	7.0	3.10	5.90	2.10
3.70	7.1	3.50	5.80	2.50
3.70	7.1	3.40	5.60	2.50
3.60	7.0	3.20	5.70	2.20
3.40	6.8	3.00	5.70	1.90
3.30	6.9	3.00	5.60	2.20
3.30	6.9	2.60	5.60	2.00
3.00	6.6	1.70	5.50	1.60
3.30	6.8	2.20	5.40	2.10
3.50	6.8	3.00	5.20	2.50
3.50	6.6	2.60	5.20	2.40
3.50	6.5	2.10	5.20	2.40
3.40	6.5	2.20	5.20	2.20
3.40	6.5	2.90	5.10	2.30
3.60	6.6	3.20	5.30	2.40
3.80	6.5	3.90	5.20	2.90
4.10	6.6	4.40	5.20	3.20
4.20	6.5	4.70	5.20	3.30
4.40	6.5	4.90	5.20	3.60
4.50	6.3	5.00	5.20	3.70
4.60	6.4	4.90	5.20	3.60
5.10	6.3	5.40	5.30	4.30
5.50	6.4	6.10	5.40	4.60
6.10	6.5	6.00	5.40	5.30
6.10	6.3	6.50	5.30	5.30
7.30	6.1	7.00	5.50	6.90
8.70	6.2	7.30	5.50	8.70
9.90	6.3	7.90	5.60	10.30
10.40	6.0	7.50	5.90	10.00
11.50	6.0	7.80	6.20	12.00
12.30	6.0	8.20	6.00	13.30
12.40	6.1	8.50	6.80	12.90
12.60	6.1	8.30	7.20	12.90
14.50	6.2	9.60	7.60	13.50

Model Output 08-03-80 Actuals





08-09 MARCH 1980



09-Ø3-80

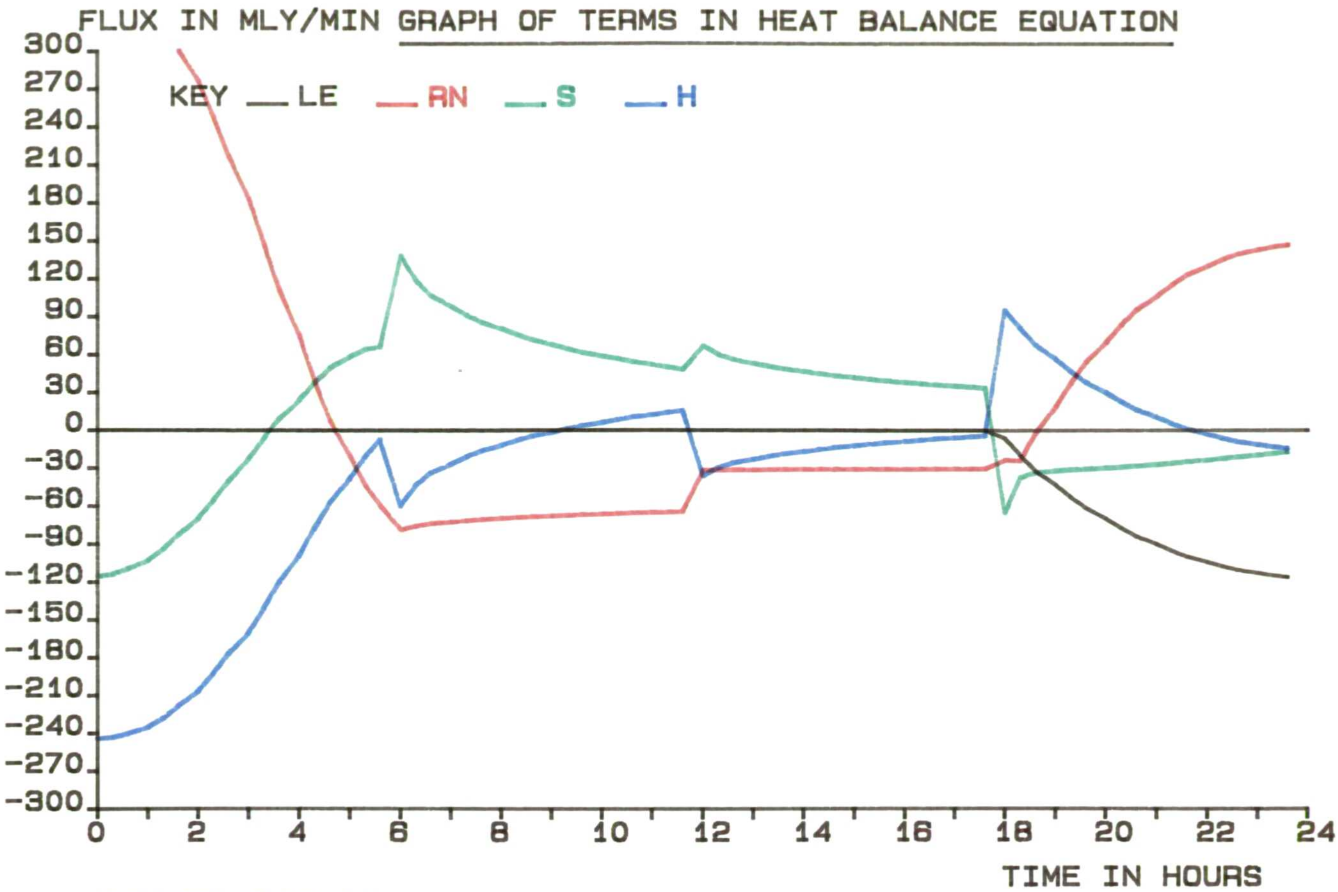
COMPUTED DATA
SAT. VAP. PRESSURE(MB)= 11.55
VAPOUR PRESSURE(MB)= 6.93
REL. HUMIDITY FRACTION = 0.60
APPROX. PRECIP. WATER(MM)= 11.0
ROAD DAMPING DEPTH(CM)= 72.
AIR DAMPING DEPTH(CM)= 2113. 3127.
AIR HEAT TRANSFER COEF.(CGS)= 0.00174 0.00353

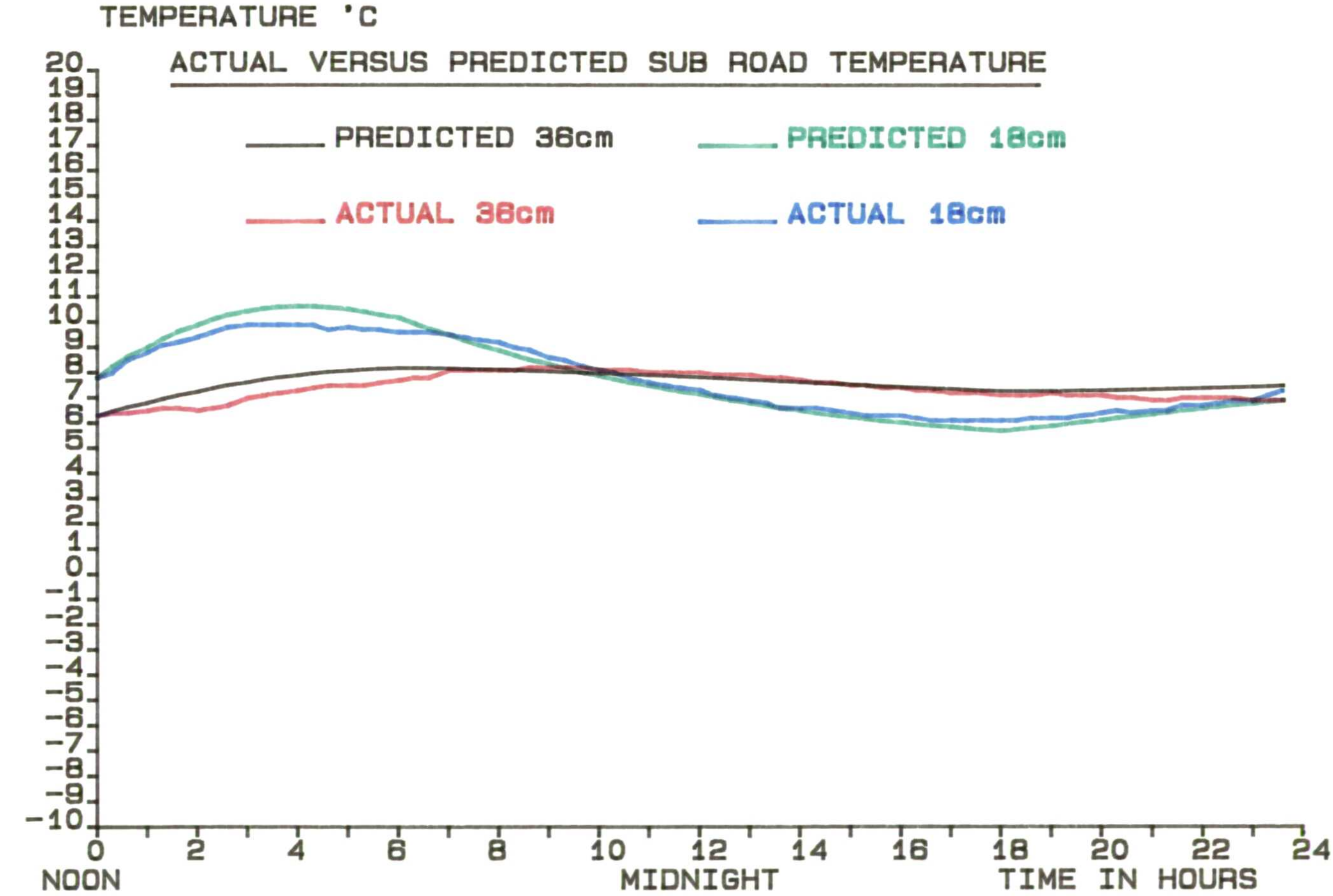
DEC	R	T36	T18	TS	UA	D	TIME WET
-3.945	0.993	279.5	281.0	14.1	266. 629.	0.5	6

SOLAR TIME	SUN	RN	S	H	LE	TD	TC (C.)	SUM	RI
		(ALL	MLY./MIN.)						
12.0	580.6	358.9	-115.	-244.	0.	14.10	18.96	1.	-0.00230
12.0	578.4	356.5	-114.	-243.	0.	16.51	18.92	0.	-0.00229
12.0	571.7	349.4	-110.	-240.	0.	17.66	18.80	0.	-0.00227
13.0	560.7	337.8	-103.	-235.	0.	18.13	18.61	0.	-0.00222
13.0	545.3	321.5	-94.	-228.	0.	18.23	18.33	0.	-0.00215
13.0	525.7	300.9	-83.	-218.	0.	18.09	17.96	0.	-0.00207
14.0	502.3	276.6	-70.	-207.	0.	17.80	17.50	0.	-0.00196
14.0	474.9	246.5	-56.	-193.	0.	17.38	16.96	0.	-0.00183
14.0	444.0	217.2	-40.	-177.	0.	16.86	16.34	0.	-0.00168
15.0	412.2	183.1	-23.	-161.	0.	16.23	15.59	0.	-0.00153
15.0	374.8	147.5	-7.	-141.	0.	15.52	14.82	0.	-0.00135
15.0	334.6	111.1	9.	-121.	0.	14.76	14.00	0.	-0.00115
16.0	292.2	75.0	24.	-99.	0.	13.97	13.17	0.	-0.00095
16.0	247.3	40.0	38.	-78.	0.	13.14	12.32	0.	-0.00075
16.0	200.0	7.8	49.	-58.	0.	12.33	11.51	0.	-0.00055
17.0	149.9	-20.3	58.	-38.	0.	11.53	10.74	0.	-0.00037
17.0	91.9	-43.3	64.	-21.	0.	10.80	10.06	0.	-0.00021
17.0	0.0	-59.5	66.	-7.	0.	10.15	9.50	0.	-0.00007
18.0	0.0	-78.7	138.	-60.	0.	8.72	7.30	0.	-0.00059
18.0	0.0	-75.5	118.	-43.	0.	7.68	6.65	0.	-0.00043
18.0	0.0	-73.6	106.	-34.	0.	6.97	6.25	0.	-0.00033
19.0	0.0	-72.2	98.	-27.	0.	6.47	5.97	0.	-0.00026
19.0	0.0	-71.1	91.	-21.	0.	6.11	5.74	0.	-0.00020
19.0	0.0	-70.2	85.	-16.	0.	5.83	5.55	0.	-0.00016
20.0	0.0	-69.3	80.	-12.	0.	5.60	5.38	0.	-0.00012
20.0	0.0	-68.6	76.	-8.	0.	5.42	5.23	0.	-0.00008
20.0	0.0	-68.0	72.	-5.	0.	5.25	5.09	0.	-0.00004
21.0	0.0	-67.4	68.	-1.	0.	5.11	4.97	0.	-0.00001
21.0	0.0	-66.8	64.	1.	0.	4.98	4.86	0.	0.00001
21.0	0.0	-66.3	61.	4.	0.	4.87	4.75	0.	0.00004
22.0	0.0	-65.9	59.	6.	0.	4.77	4.66	0.	0.00006
22.0	0.0	-65.4	57.	9.	0.	4.66	4.56	0.	0.00009
22.0	0.0	-65.0	54.	11.	0.	4.57	4.48	0.	0.00011
23.0	0.0	-64.7	52.	13.	0.	4.49	4.41	0.	0.00012
23.0	0.0	-64.3	50.	14.	0.	4.41	4.34	0.	0.00014
23.0	0.0	-64.0	48.	16.	0.	4.34	4.27	0.	0.00016
0.0	0.0	-31.5	67.	-36.	0.	4.03	3.72	0.	-0.00003
0.0	0.0	-31.3	60.	-29.	0.	3.81	3.59	0.	-0.00003
0.0	0.0	-31.1	56.	-26.	0.	3.66	3.52	0.	-0.00002
1.0	0.0	-31.0	53.	-23.	0.	3.56	3.46	0.	-0.00002
1.0	0.0	-30.9	51.	-20.	0.	3.49	3.41	0.	-0.00002
1.0	0.0	-30.8	48.	-18.	0.	3.43	3.37	0.	-0.00002
2.0	0.0	-30.7	46.	-16.	0.	3.38	3.34	0.	-0.00002
2.0	0.0	-30.7	45.	-15.	0.	3.34	3.30	0.	-0.00001
2.0	0.0	-30.6	43.	-13.	0.	3.31	3.27	0.	-0.00001
3.0	0.0	-30.5	42.	-12.	0.	3.28	3.25	0.	-0.00001
3.0	0.0	-30.5	40.	-11.	0.	3.25	3.22	0.	-0.00001
3.0	0.0	-30.4	39.	-9.	0.	3.22	3.20	0.	-0.00001
4.0	0.0	-30.4	38.	-6.	0.	3.20	3.18	0.	-0.00001
4.0	0.0	-30.4	37.	-7.	0.	3.18	3.16	0.	-0.00001
4.0	0.0	-30.3	36.	-6.	0.	3.16	3.14	0.	-0.00001
5.0	0.0	-30.3	35.	-5.	0.	3.14	3.12	0.	-0.00001
5.0	0.0	-30.2	34.	-5.	0.	3.12	3.10	0.	0.00000
5.0	0.0	-30.2	33.	-4.	0.	3.11	3.09	0.	0.00000
6.0	0.0	-23.3	-65.	95.	-6.	4.28	5.44	-6.	0.00009
6.0	0.4	-23.9	-38.	81.	-19.	5.00	5.72	-26.	0.00008
6.0	106.0	-2.1	-33.	68.	-32.	5.49	5.98	-58.	0.00006
7.0	144.1	18.4	-32.	57.	-43.	5.84	6.20	-101.	0.00005
7.0	163.0	37.0	-31.	47.	-53.	6.12	6.39	-154.	0.00004
7.0	175.6	54.0	-30.	38.	-62.	6.34	6.56	-216.	0.00004
8.0	185.1	69.5	-30.	30.	-70.	6.53	6.72	-286.	0.00003
8.0	192.5	83.4	-29.	23.	-77.	6.70	6.86	-363.	0.00002
8.0	198.7	95.6	-28.	16.	-84.	6.84	6.99	-447.	0.00002
9.0	203.9	106.5	-27.	11.	-90.	6.97	7.10	-537.	0.00002
9.0	208.2	115.9	-26.	5.	-95.	7.09	7.20	-632.	0.00001
9.0	211.9	123.9	-25.	1.	-100.	7.19	7.29	-732.	0.00000
10.0	215.0	130.6	-24.	-3.	-104.	7.28	7.37	-836.	[illegible]
10.0	217.5	136.1	-22.	-6.	-108.	7.36	7.43	-944.	-0.00001
10.0	219.6	140.5	-21.	-9.	-111.	7.42	7.49	-1055.	-0.00001
11.0	221.1	143.9	-20.	-11.	-113.	7.48	7.53	-1168.	-0.00001
11.0	222.2	146.2	-18.	-13.	-115.	7.52	7.57	-1283.	-0.00001
11.0	222.9	147.6	-17.	-14.	-116.	7.56	7.60	-1399.	-0.00001

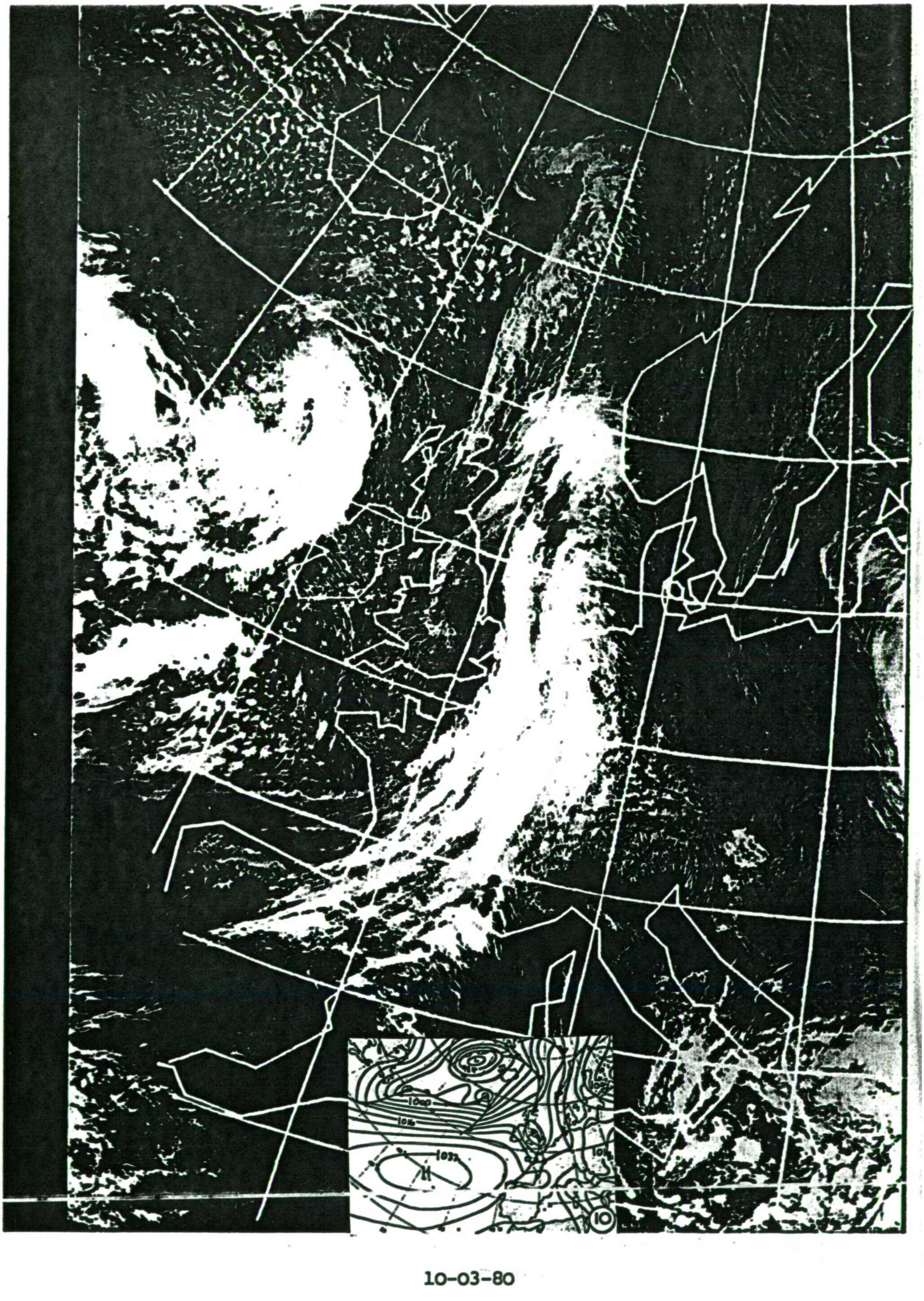
TO	T36	Air	T18	Tslab
14.10	6.3	9.10	7.80	14.00
15.50	6.4	9.20	8.00	16.40
15.80	6.4	9.40	8.50	16.30
16.20	6.5	9.10	8.80	16.50
16.30	6.6	9.20	9.10	16.00
14.00	6.6	9.20	9.20	14.00
15.50	6.5	9.30	9.40	16.00
14.30	6.6	9.20	9.60	14.50
13.00	6.7	8.50	9.80	12.00
13.00	7.0	9.30	9.90	12.90
12.40	7.1	9.10	9.90	12.40
13.10	7.2	9.20	9.90	13.10
12.50	7.3	9.30	9.90	12.50
12.20	7.4	9.00	9.90	11.90
11.00	7.5	9.10	9.70	11.20
11.30	7.5	9.20	9.80	10.70
10.90	7.5	9.00	9.70	10.20
10.10	7.6	8.20	9.70	9.10
9.70	7.7	8.20	9.00	8.80
9.60	7.8	8.40	9.60	8.60
9.40	7.8	8.30	9.60	8.00
9.30	8.1	7.40	9.50	8.20
8.50	8.1	6.80	9.40	7.30
7.90	8.1	6.50	9.30	6.70
7.50	8.1	6.00	9.20	6.20
7.10	8.1	5.20	9.00	5.80
6.80	8.2	4.40	8.90	5.30
6.40	8.2	4.20	8.60	4.90
6.20	8.2	4.40	8.50	4.80
5.90	8.2	3.70	8.30	4.50
5.40	8.1	1.90	8.10	4.20
5.20	8.1	1.80	8.00	3.80
5.00	8.1	2.00	7.80	3.80
4.90	8.0	2.40	7.60	3.70
4.80	8.0	1.80	7.50	3.60
4.50	8.0	1.10	7.40	3.50
4.50	8.0	1.30	7.30	3.50
4.30	7.9	1.30	7.10	3.30
4.30	7.9	1.50	7.00	3.40
4.30	7.9	1.20	6.90	3.40
4.20	7.8	0.90	6.80	3.40
4.30	7.6	1.10	6.60	3.40
4.30	7.7	2.30	6.60	3.50
4.30	7.6	2.30	6.60	3.60
4.50	7.6	2.60	6.50	3.70
4.50	7.5	2.70	6.40	3.70
4.50	7.5	3.20	6.30	3.70
4.50	7.4	3.30	6.30	3.70
4.60	7.4	3.40	6.30	3.80
4.60	7.3	3.70	6.20	3.80
4.60	7.3	3.70	6.10	3.80
4.70	7.2	4.20	6.10	3.90
4.90	7.2	4.80	6.10	4.20
5.00	7.2	5.30	6.10	4.30
5.20	7.1	5.60	6.10	4.50
5.40	7.1	5.70	6.10	4.70
5.50	7.1	5.70	6.20	4.70
5.90	7.2	6.40	6.20	5.10
6.20	7.1	6.40	6.20	5.40
6.40	7.1	6.40	6.30	5.60
6.50	7.1	6.30	6.40	5.90
6.70	7.0	6.40	6.50	6.20
7.00	7.0	6.60	6.40	6.50
7.10	6.9	6.70	6.50	6.50
7.30	6.9	7.00	6.50	6.90
7.30	7.0	6.90	6.70	6.70
7.90	7.0	7.50	6.70	7.50
8.50	7.0	8.50	6.80	8.30
8.20	7.0	8.00	6.90	8.00
8.70	6.9	8.00	6.90	8.90
11.70	6.9	9.20	7.10	12.70
12.60	6.9	9.20	7.30	12.30

Model Output 09-10-80 Actuals





09-10 MARCH 1980



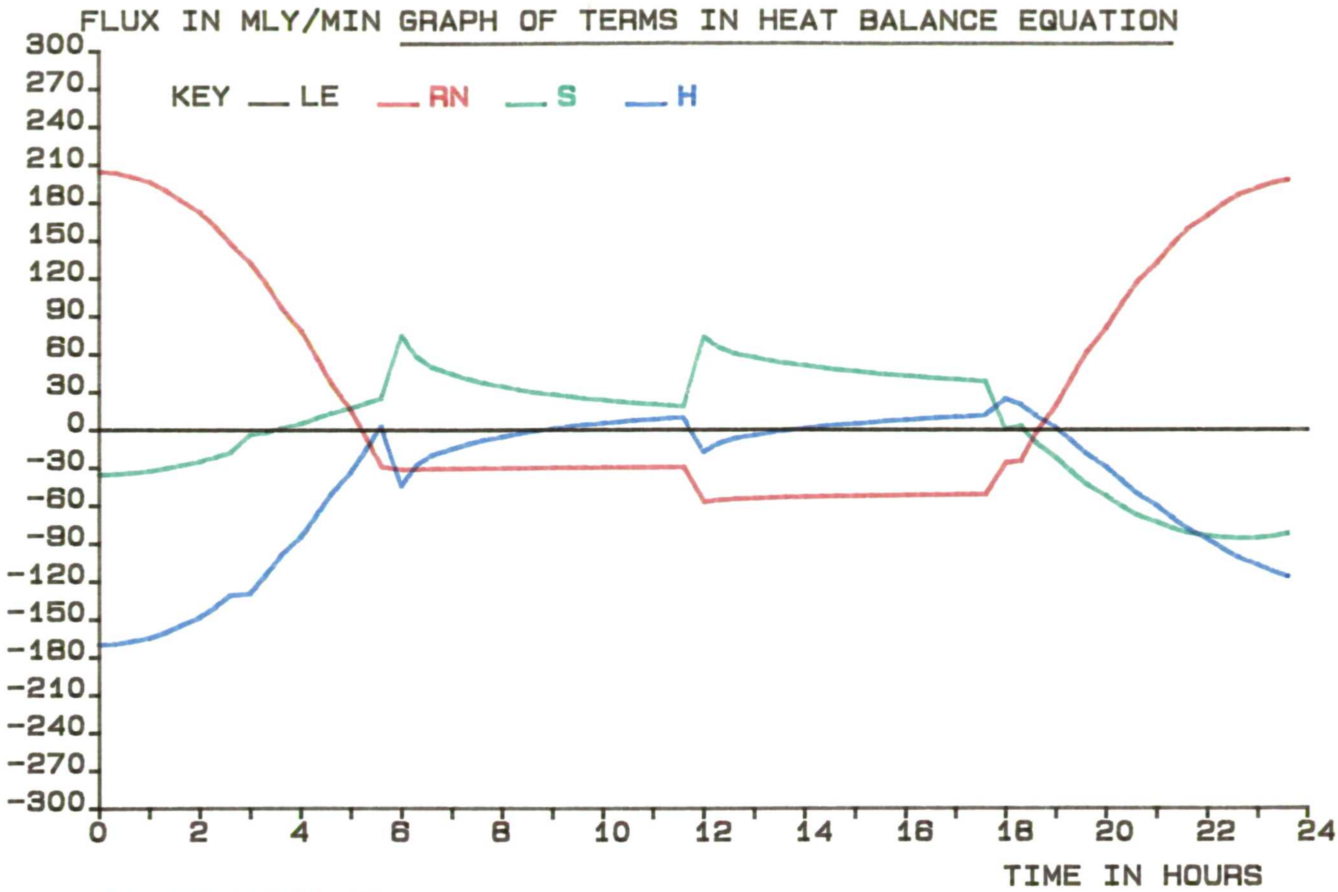
10-03-80

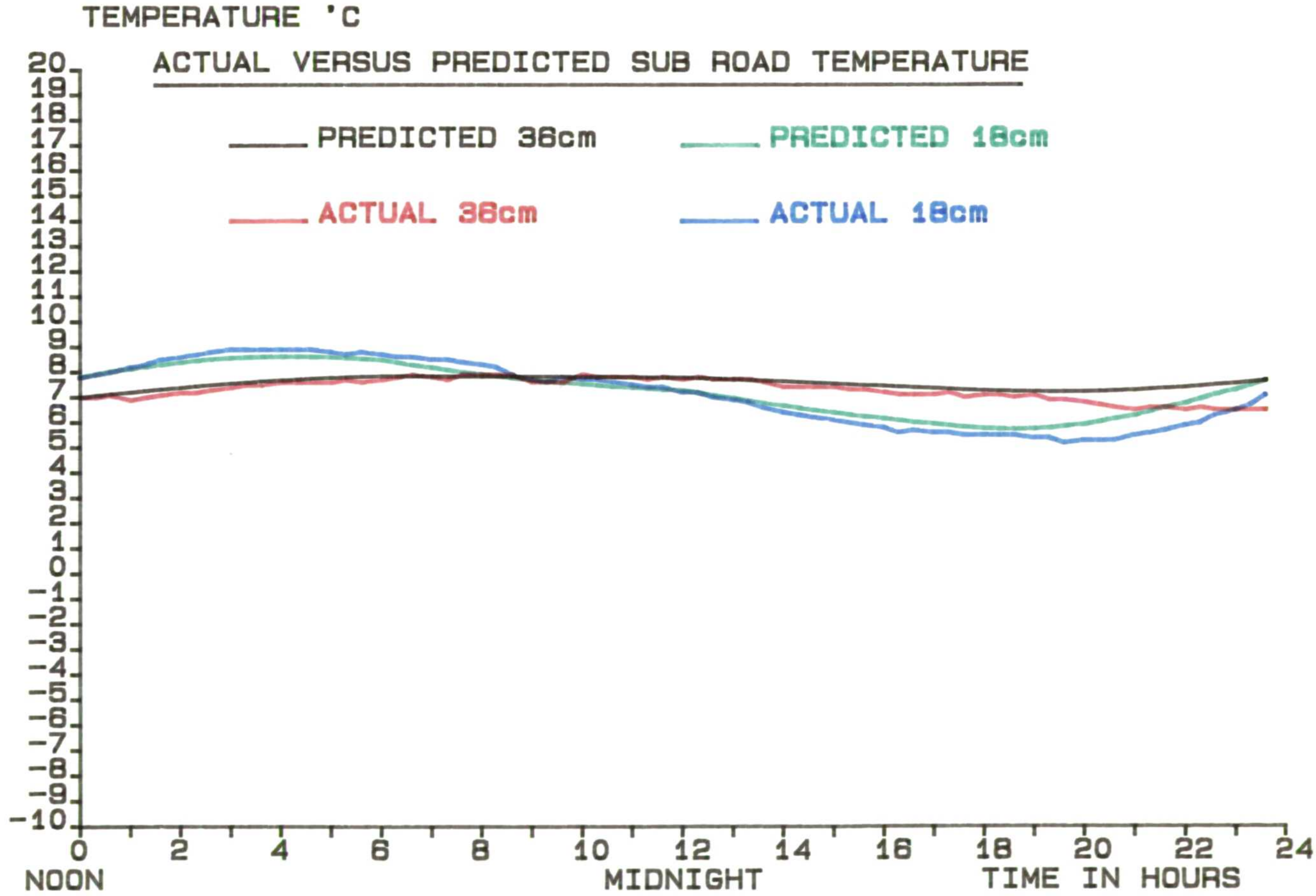
SAT. VAP. PRESSURE(MB)= 10.94
VAPOUR PRESSURE(MB)= 7.77
REL. HUMIDITY FRACTION = 0.71
APPROX. PRECIP. WATER(MM)= 12.3
ROAD DAMPING DEPTH(CM)= 72.
AIR DAMPING DEPTH(CM)= 3618. 1743.
AIR HEAT TRANSFER COEF.(CGS)= 0.00460 0.00123

DEC	R	T36	T18	TS	UA	D	TIME NET
-3.552	0.99428	0.2	281.0	13.4	865. 174.	0.5	0

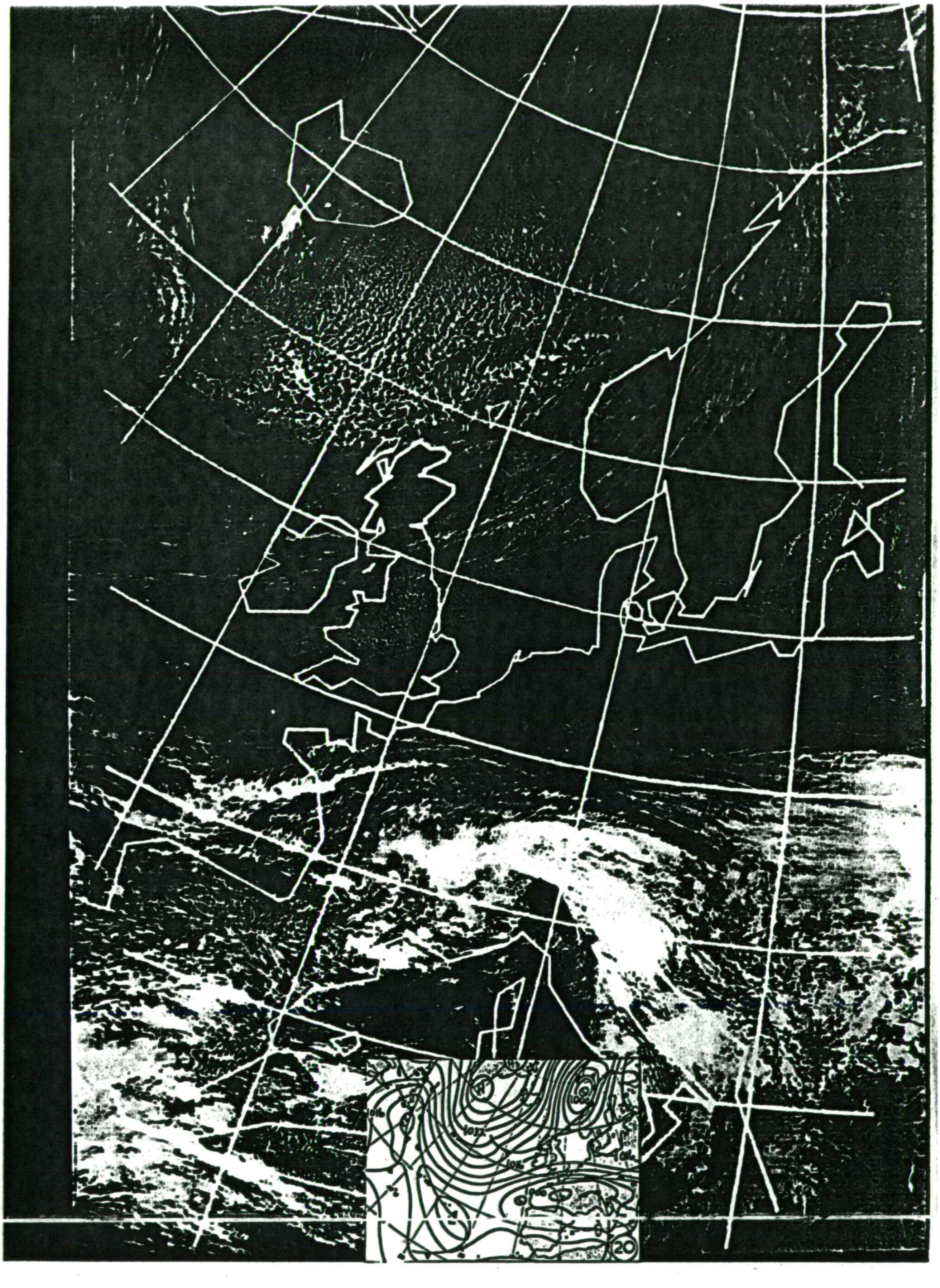
SOLAR TIME	SUN	RN	S	H	LE	TD	TC	SUM	RI	TO	T36	Air	T18	Tslab
			(ALL MLY./MIN.)				(C.)							
12.0	303.6	204.2	-35.	-170.	0.	13.40	11.22	1.	-0.00007	13.40	7.0	9.10	7.80	13.60
12.0	303.0	203.4	-35.	-169.	0.	12.31	11.21	0.	-0.00006	12.40	7.0	8.20	7.90	12.30
12.0	301.1	200.7	-34.	-167.	0.	11.75	11.19	0.	-0.00006	11.60	7.1	7.60	8.00	11.00
13.0	298.0	196.3	-33.	-164.	0.	11.45	11.14	0.	-0.00006	10.90	6.9	7.60	8.20	10.40
13.0	293.6	190.1	-30.	-160.	0.	11.26	11.08	0.	-0.00006	11.80	7.0	7.90	8.30	11.60
13.0	288.0	182.1	-28.	-155.	0.	11.13	11.00	0.	-0.00006	11.50	7.1	8.50	8.50	11.20
14.0	281.3	172.4	-25.	-148.	0.	11.01	10.90	0.	-0.00006	11.60	7.2	8.50	8.60	11.20
14.0	273.2	160.8	-22.	-140.	0.	10.89	10.77	0.	-0.00005	11.20	7.2	8.40	8.70	10.60
14.0	264.0	147.5	-18.	-130.	0.	10.76	10.63	0.	-0.00005	11.20	7.3	8.30	8.80	10.60
15.0	254.0	132.0	-3.	-129.	0.	10.49	10.21	0.	-0.00005	10.90	7.4	8.30	8.90	10.20
15.0	242.2	115.5	-2.	-114.	0.	10.24	9.99	0.	-0.00004	10.40	7.5	8.20	8.90	9.60
15.0	229.1	97.4	1.	-100.	0.	10.00	9.77	0.	-0.00004	10.40	7.5	8.10	8.90	9.70
16.0	214.5	78.2	5.	-84.	0.	9.77	9.53	0.	-0.00003	10.30	7.6	8.20	8.90	9.50
16.0	197.8	57.9	9.	-68.	0.	9.53	9.29	0.	-0.00003	10.30	7.6	8.00	8.90	9.50
16.0	178.0	36.7	14.	-51.	0.	9.28	9.03	0.	-0.00002	9.80	7.6	7.90	8.90	9.10
17.0	152.6	15.1	18.	-33.	0.	9.02	8.77	0.	-0.00001	9.40	7.6	7.70	8.80	8.50
17.0	112.3	-6.9	21.	-15.	0.	8.76	8.49	0.	-0.00001	9.10	7.7	7.50	8.70	8.20
17.0	7.6	-29.3	25.	3.	0.	8.49	8.21	0.	0.00000	8.90	7.6	7.40	8.80	7.90
18.0	0.0	-31.4	75.	-44.	0.	7.66	6.83	0.	-0.00002	8.70	7.7	7.30	8.70	7.60
18.0	0.0	-30.8	58.	-28.	0.	7.12	6.58	0.	-0.00001	8.40	7.6	6.90	8.60	7.30
18.0	0.0	-30.6	49.	-20.	0.	6.79	6.46	0.	-0.00001	8.20	7.9	6.90	8.60	7.10
19.0	0.0	-30.4	44.	-15.	0.	6.59	6.38	0.	-0.00001	8.10	7.8	6.60	8.50	6.90
19.0	0.0	-30.3	40.	-11.	0.	6.46	6.33	0.	0.00000	7.70	7.7	6.30	8.50	6.70
19.0	0.0	-30.2	37.	-8.	0.	6.37	6.28	0.	0.00000	7.40	7.9	6.20	8.40	6.40
20.0	0.0	-30.1	34.	-5.	0.	6.30	6.24	0.	0.00000	7.00	7.9	5.70	8.30	5.90
20.0	0.0	-30.0	32.	-3.	0.	6.25	6.20	0.	0.00000	6.70	7.9	5.80	8.20	5.60
20.0	0.0	-30.0	30.	-1.	0.	6.21	6.17	0.	0.00000	6.70	7.9	6.00	7.90	5.70
21.0	0.0	-29.9	28.	1.	0.	6.18	6.14	0.	0.00000	6.60	7.6	5.90	7.70	5.50
										6.50	7.6	5.70	7.60	5.60
21.0	0.0	-29.9	26.	3.	0.	6.15	6.12	0.	0.00000	6.40	7.6	5.50	7.60	5.50
21.0	0.0	-29.8	25.	4.	0.	6.12	6.10	0.	0.00000	6.50	7.9	5.60	7.70	5.50
22.0	0.0	-29.8	24.	5.	0.	6.10	6.08	0.	0.00000	6.50	7.6	5.70	7.70	5.60
22.0	0.0	-29.7	22.	7.	0.	6.08	6.06	0.	0.00000	6.20	7.8	5.10	7.60	5.10
22.0	0.0	-29.7	21.	8.	0.	6.06	6.05	0.	0.00000	5.80	7.6	4.70	7.50	4.70
23.0	0.0	-29.7	20.	9.	0.	6.05	6.03	0.	0.00000	5.40	7.7	4.80	7.40	4.30
23.0	0.0	-29.6	19.	9.	0.	6.03	6.02	0.	0.00000	5.00	7.8	4.40	7.40	3.80
23.0	0.0	-29.6	19.	10.	0.	6.02	6.01	0.	0.00000	4.80	7.7	4.00	7.20	3.50
0.0	0.0	-56.9	74.	-17.	0.	5.33	4.65	0.	-0.00054	4.50	7.8	4.10	7.20	3.30
0.0	0.0	-55.5	65.	-11.	0.	4.80	4.27	0.	-0.00033	4.30	7.7	4.20	7.00	3.20
0.0	0.0	-54.7	61.	-7.	0.	4.43	4.05	0.	-0.00021	4.10	7.7	3.70	6.90	3.00
1.0	0.0	-54.1	57.	-4.	0.	4.16	3.90	0.	-0.00013	3.80	7.7	3.60	6.80	2.70
1.0	0.0	-53.6	55.	-2.	0.	3.98	3.79	0.	-0.00006	3.70	7.6	3.60	6.60	2.70
1.0	0.0	-53.3	53.	0.	0.	3.83	3.69	0.	-0.00001	3.50	7.4	3.60	6.40	2.20
2.0	0.0	-52.9	51.	1.	0.	3.72	3.60	0.	0.00004	3.30	7.4	3.40	6.30	2.20
2.0	0.0	-52.7	49.	3.	0.	3.62	3.53	0.	0.00008	3.10	7.4	3.30	6.20	2.10
2.0	0.0	-52.4	48.	4.	0.	3.54	3.45	0.	0.00012	3.00	7.4	3.30	6.10	2.60
3.0	0.0	-52.1	46.	5.	0.	3.46	3.39	0.	0.00016	3.10	7.3	3.30	6.00	2.00
3.0	0.0	-51.9	45.	6.	0.	3.40	3.33	0.	0.00019	3.10	7.3	3.40	5.90	2.00
3.0	0.0	-51.7	44.	7.	0.	3.33	3.27	0.	0.00022	3.10	7.2	3.30	5.80	2.10
4.0	0.0	-51.5	43.	8.	0.	3.28	3.22	0.	0.00025	3.40	7.1	3.10	5.60	2.10
4.0	0.0	-51.3	42.	9.	0.	3.22	3.17	0.	0.00028	3.10	7.1	3.30	5.70	2.10
4.0	0.0	-51.1	41.	10.	0.	3.17	3.13	0.	0.00031	3.20	7.1	3.30	5.60	2.10
5.0	0.0	-51.0	40.	10.	0.	3.13	3.08	0.	0.00033	3.10	7.2	3.10	5.60	2.00
5.0	0.0	-50.8	39.	11.	0.	3.09	3.04	0.	0.00035	3.10	7.0	3.00	5.50	1.80
5.0	0.0	-50.7	38.	12.	0.	3.05	3.01	0.	0.00037	3.00	7.1	2.80	5.50	1.70
6.0	0.0	-25.8	0.	25.	0.	3.46	3.87	0.	0.00078	3.10	7.1	2.70	5.50	1.70
6.0	16.0	-24.5	3.	20.	0.	3.79	4.12	0.	0.00064	3.20	7.0	2.60	5.50	1.60
6.0	115.2	-2.3	-10.	12.	0.	4.20	4.61	0.	0.00037	3.50	7.1	2.60	5.40	2.00
7.0	154.4	19.3	-22.	2.	0.	4.68	5.16	0.	0.00007	3.60	6.9	3.10	5.40	2.70
7.0	179.4	40.4	-33.	-8.	0.	5.20	5.73	0.	-0.00025					
7.0	199.0	60.8	-43.	-18.	0.	5.76	6.31	0.	-0.00057	4.30	6.9	3.40	5.20	3.60
8.0	215.7	80.6	-52.	-29.	0.	6.33	6.90	0.	-0.00090	5.00	6.8	3.80	5.30	3.60
8.0	230.3	99.1	-60.	-39.	0.	6.90	7.48	0.	-0.00122	5.20	6.7	4.00	5.30	4.10
8.0	243.3	116.4	-67.	-50.	0.	7.48	8.05	0.	-0.00153	5.90	6.6	4.50	5.30	5.00
9.0	255.1	132.2	-73.	-60.	0.	8.04	8.60	0.	-0.00183	6.40	6.5	5.00	5.50	5.70
9.0	265.6	146.4	-78.	-69.	0.	8.59	9.13	0.	-0.00212	7.10	6.6	5.40	5.60	6.60
9.0	274.8	159.0	-82.	-78.	0.	9.10	9.62	0.	-0.00238	7.50	6.6	5.90	5.70	7.00
10.0	282.9	169.9	-84.	-86.	0.	9.59	10.08	0.	-0.00263	7.90	6.5	6.70	5.90	[illegible]
10.0	289.7	179.0	-86.	-94.	0.	10.04	10.50	0.	-0.00286	9.30	6.6	7.40	6.00	9.20
10.0	295.3	186.3	-86.	-101.	0.	10.46	10.87	0.	-0.00307	9.80	6.5	7.40	6.30	9.70
11.0	299.7	192.0	-86.	-107.	0.	10.83	11.21	0.	-0.00325	10.40	6.5	7.60	6.50	10.50
11.0	302.9	195.9	-84.	-112.	0.	11.16	11.49	0.	-0.00340	11.00	6.5	8.30	6.70	11.30
11.0	304.8	198.0	-82.	-116.	0.	11.45	11.73	0.	-0.00353	11.80	6.5	8.60	7.10	12.30

Model Output 10-03-80 Actuals





10-11 MARCH 1980



20-03-80

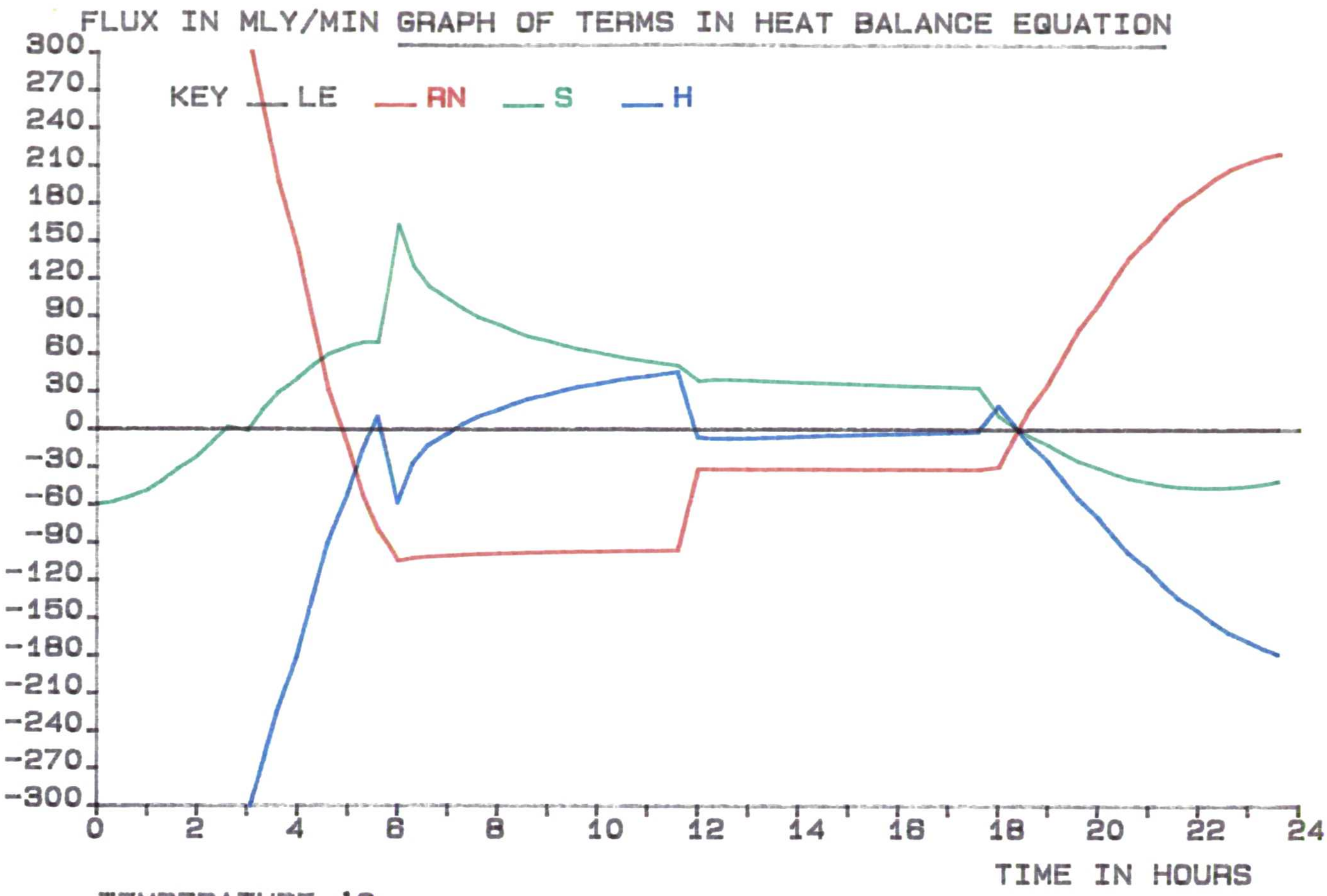
COMPUTED DATA

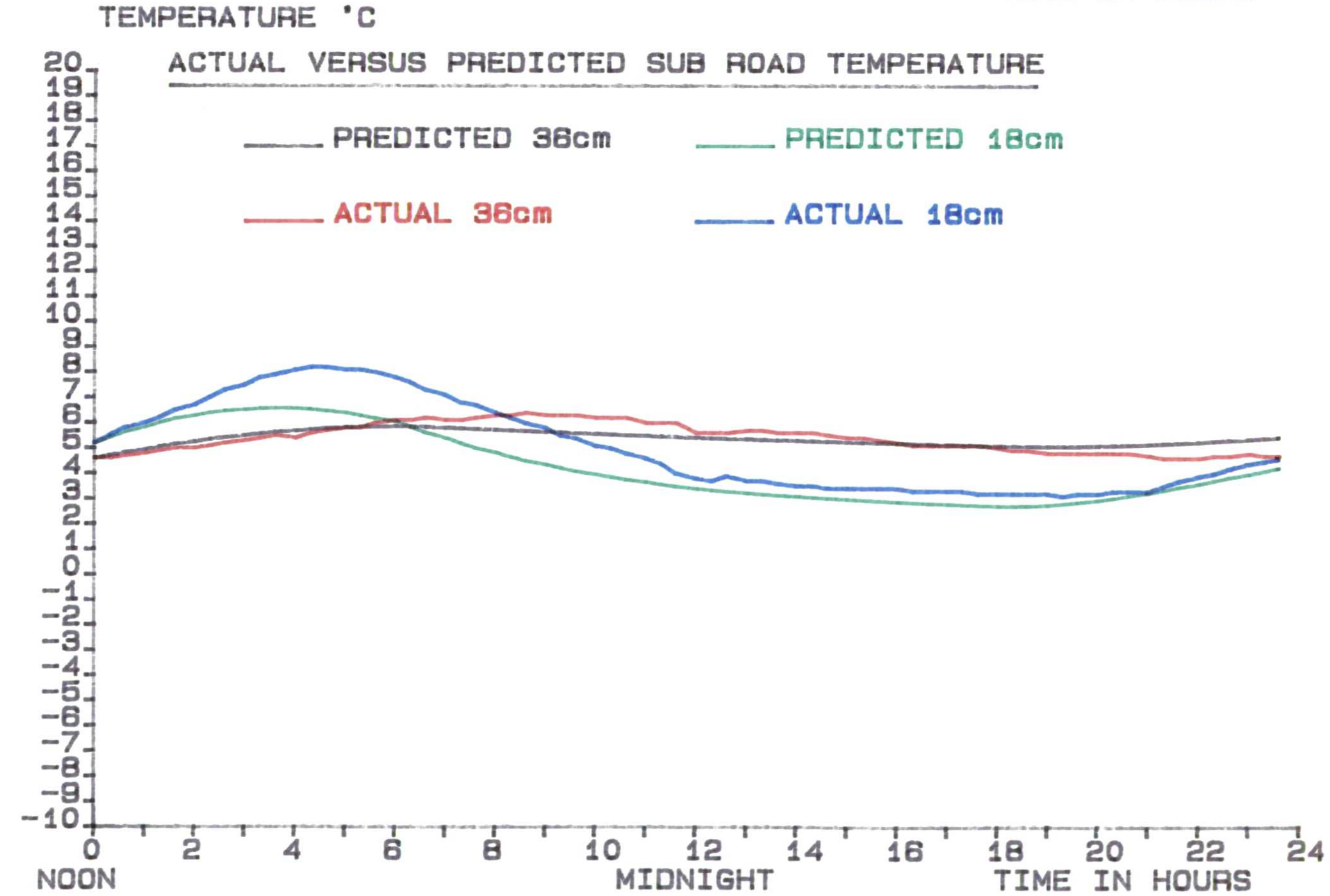
SAT. VAP. PRESSURE(MB)= 7.58
VAPOUR PRESSURE(MB)= 4.39
REL. HUMIDITY FRACTION .= 0.58
APPROX. PRECIP. WATER(MM)= 7.2
ROAD DAMPING DEPTH(CM)= 72.
AIR DAMPING DEPTH(CM)= 3697. 2592.
AIR HEAT TRANSFER COEF.(CGS)= 0.00478 0.00251

DEC	R	T36	T18	TS	UA	D	TIME WET
0.395	0.996	277.8	278.4	9.2	907. 417.	0.5	0

SOLAR TIME	SUN	RN	S (ALL MLY./MIN.)	H	LE	TD	TC (C.)	SUM	RI	TO	T36	Air	T18	Tslab
12.0	886.7	584.6	-60.	-525.	0.	9.20	10.99	1.	-0.00018	9.20	4.60	1.70	5.20	[illegible]
12.0	883.2	580.9	-58.	-523.	0.	10.08	10.95	0.	-0.00018	9.50	4.60	1.70	5.50	[illegible]
12.0	872.6	569.9	-55.	-516.	0.	10.46	10.85	0.	-0.00018	10.10	4.70	2.70	5.80	10.[illegible]
13.0	855.5	552.1	-49.	-504.	0.	10.57	10.67	0.	-0.00017	11.00	4.80	3.40	6.00	11.[illegible]
13.0	831.3	526.9	-41.	-486.	0.	10.49	10.42	0.	-0.00017	12.00	4.90	3.10	6.20	11.[illegible]
13.0	800.5	495.1	-32.	-463.	0.	10.29	10.09	0.	-0.00016	12.10	5.00	3.20	6.50	11.5[illegible]
14.0	763.9	457.3	-22.	-436.	0.	9.99	9.69	0.	-0.00015	13.10	5.00	4.10	6.70	12.[illegible]
14.0	721.0	413.4	-10.	-403.	0.	9.61	9.22	0.	-0.00014	13.20	5.10	3.40	7.00	12.[illegible]
14.0	672.7	364.6	2.	-367.	0.	9.15	8.69	0.	-0.00013	13.50	5.20	4.10	7.30	13.[illegible]
15.0	622.3	311.7	-2.	-311.	0.	8.81	8.48	0.	-0.00011	13.50	5.30	4.10	7.50	12.9[illegible]
15.0	564.3	255.3	15.	-271.	0.	8.35	7.90	0.	-0.00009	13.30	5.40	4.30	7.80	12.7[illegible]
15.0	502.3	197.4	29.	-227.	0.	7.81	7.26	0.	-0.00008	12.60	5.50	3.90	7.90	11.[illegible]
16.0	437.2	139.8	41.	-181.	0.	7.20	6.60	0.	-0.00006	12.10	5.40	3.80	8.10	11.2[illegible]
16.0	369.0	83.7	51.	-135.	0.	6.57	5.93	0.	-0.00005	11.20	5.60	3.90	8.20	10.30
16.0	298.8	31.4	60.	-92.	0.	5.93	5.30	0.	-0.00003	10.30	5.70	3.60	8.20	9.10
17.0	227.5	-14.8	66.	-52.	0.	5.33	4.72	0.	-0.00002	9.50	5.80	3.30	8.10	7.20
17.0	155.4	-52.9	69.	-17.	0.	4.77	4.22	0.	-0.00001	8.60	5.80	3.10	8.10	6.80
17.0	83.4	-80.4	69.	10.	0.	4.30	3.82	0.	0.00000	7.60	6.00	2.80	8.00	5.80
18.0	2.7	-104.7	163.	-58.	0.	2.76	1.22	0.	-0.00002	6.60	6.10	2.20	7.80	4.70
18.0	0.0	-102.5	130.	-28.	0.	1.76	0.77	0.	-0.00001	5.60	6.10	2.10	7.60	3.90
18.0	0.0	-101.3	113.	-13.	0.	1.16	0.55	0.	0.00000	4.90	6.20	1.40	7.30	3.1[illegible]
19.0	0.0	-100.6	103.	-3.	0.	0.79	0.42	0.	0.00000	4.20	6.10	1.00	7.10	2.50
19.0	0.0	-100.0	95.	4.	0.	0.55	0.31	0.	0.00000	3.70	6.10	0.90	6.80	2.80
19.0	0.0	-99.5	89.	10.	0.	0.39	0.22	0.	0.00000	4.20	6.20	0.60	6.70	1.60
20.0	0.0	-99.1	83.	15.	0.	0.27	0.15	0.	0.00001	2.90	6.30	0.30	6.40	1.40
20.0	0.0	-98.7	78.	20.	0.	0.17	0.08	0.	0.00001	2.50	6.30	0.20	6.20	0.9[illegible]
20.0	0.0	-98.4	74.	24.	0.	0.10	0.02	0.	0.00001	2.10	6.40	0.00	6.00	0.5[illegible]
21.0	0.0	-98.1	70.	28.	0.	0.03	-0.03	0.	0.00001	2.10	6.30	-0.30	5.80	0.6[illegible]
21.0	0.0	-97.9	66.	31.	0.	-0.02	-0.08	0.	0.00001	1.80	6.30	-0.60	5.50	0.10
21.0	0.0	-97.6	63.	34.	0.	-0.07	-0.12	0.	0.00001	1.40	6.30	-0.70	5.40	-0.1[illegible]
22.0	0.0	-97.4	61.	36.	0.	-0.11	-0.15	0.	0.00001	1.10	6.20	-0.90	5.10	-0.[illegible]
22.0	0.0	-97.2	58.	38.	0.	-0.15	-0.19	0.	0.00001	0.90	6.20	-0.90	5.00	-0.[illegible]
22.0	0.0	-97.1	56.	40.	0.	-0.18	-0.22	0.	0.00001	0.70	6.20	-1.00	4.80	-0.[illegible]
23.0	0.0	-96.9	54.	42.	0.	-0.21	-0.24	0.	0.00001	0.50	6.00	-1.00	4.60	-0.9[illegible]
23.0	0.0	-96.8	52.	44.	0.	-0.24	-0.27	0.	0.00002	0.30	6.00	-1.20	4.40	-1.3[illegible]
23.0	0.0	-96.7	50.	46.	0.	-0.27	-0.29	0.	0.00002	0.10	6.00	-1.30	4.00	-1.4[illegible]
0.0	0.0	-32.3	38.	-7.	0.	-0.16	-0.06	0.	-0.00002	-0.30	5.60	-1.60	3.80	-1.7[illegible]
0.0	0.0	-32.4	39.	-8.	0.	-0.10	-0.03	0.	-0.00002	-0.20	5.60	-1.30	3.70	-1.5[illegible]
0.0	0.0	-32.4	39.	-8.	0.	-0.07	-0.03	0.	-0.00002	0.00	5.60	-1.20	3.90	-1.3[illegible]
1.0	0.0	-32.4	39.	-7.	0.	-0.05	-0.04	0.	-0.00002	0.40	5.70	-1.20	3.70	-0.80
1.0	0.0	-32.3	38.	-7.	0.	-0.05	-0.06	0.	-0.00002	0.50	5.70	-1.10	3.70	-0.80
1.0	0.0	-32.3	38.	-6.	0.	-0.06	-0.07	0.	-0.00002	0.70	5.60	-0.50	3.60	-0.1[illegible]
2.0	0.0	-32.3	37.	-6.	0.	-0.07	-0.08	0.	-0.00002	0.80	5.60	-0.30	3.50	-0.2[illegible]
2.0	0.0	-32.3	37.	-5.	0.	-0.08	-0.09	0.	-0.00002	1.00	5.60	-0.30	3.50	-0.1[illegible]
2.0	0.0	-32.2	36.	-5.	0.	-0.09	-0.11	0.	-0.00001	1.00	5.50	-0.20	3.40	0.00
3.0	0.0	-32.2	36.	-4.	0.	-0.11	-0.12	0.	-0.00001	1.10	5.40	-0.20	3.40	0.00
3.0	0.0	-32.2	36.	-4.	0.	-0.12	-0.13	0.	-0.00001	1.10	5.40	-0.20	3.40	0.10
3.0	0.0	-32.2	35.	-4.	0.	-0.13	-0.14	0.	-0.00001	1.10	5.30	0.00	3.40	0.20
4.0	0.0	-32.1	35.	-3.	0.	-0.14	-0.15	0.	-0.00001	1.20	5.20	-0.20	3.40	0.10
4.0	0.0	-32.1	34.	-3.	0.	-0.15	-0.16	0.	-0.00001	1.20	5.10	-0.20	3.30	0.20
4.0	0.0	-32.1	34.	-3.	0.	-0.16	-0.17	0.	-0.00001	1.30	5.10	0.00	3.30	0.20
5.0	0.0	-32.1	34.	-2.	0.	-0.17	-0.18	0.	-0.00001	1.30	5.10	0.00	3.30	0.20
5.0	0.0	-32.1	33.	-2.	0.	-0.18	-0.19	0.	-0.00001	1.30	5.10	-0.10	3.30	0.20
5.0	0.0	-32.0	33.	-2.	0.	-0.19	-0.20	0.	0.00000	1.30	5.10	-0.10	3.20	0.10
6.0	12.4	-29.9	10.	19.	0.	0.08	0.34	0.	0.00006	1.30	5.00	-0.20	3.20	0.00
6.0	114.2	-7.4	2.	4.	0.	0.41	0.74	0.	0.00001	1.30	4.90	-0.20	3.20	0.10
6.0	154.3	14.9	-5.	-10.	0.	0.77	1.14	0.	-0.00003	1.40	4.90	-0.30	3.20	0.10
7.0	180.2	37.0	-13.	-25.	0.	1.16	1.55	0.	-0.00007	1.50	4.80	-0.20	3.20	0.30
7.0	200.5	58.8	-19.	-40.	0.	1.56	1.96	0.	-0.00012	1.70	4.80	0.00	3.10	0.60
7.0	217.9	79.9	-25.	-55.	0.	1.97	2.38	0.	-0.00016	2.00	4.80	0.00	3.20	0.70
8.0	233.4	100.1	-31.	-70.	0.	2.38	2.78	0.	-0.00020	2.50	4.80	0.30	3.20	1.60
8.0	247.3	119.1	-35.	-84.	0.	2.78	3.18	0.	-0.00024	3.00	4.80	0.50	3.30	2.30
8.0	259.9	136.6	-39.	-98.	0.	3.17	3.56	0.	-0.00028	3.80	4.80	1.00	3.30	3.30
9.0	271.4	152.7	-42.	-111.	0.	3.54	3.92	0.	-0.00032	4.70	4.70	0.90	3.30	4.60
9.0	281.6	167.1	-44.	-123.	0.	3.90	4.25	0.	-0.00036	4.70	4.60	0.90	3.50	4.50
9.0	290.7	179.8	-46.	-134.	0.	4.23	4.56	0.	-0.00039	5.10	4.60	0.80	3.70	4.90
10.0	298.7	190.9	-47.	-145.	0.	4.54	4.85	0.	-0.00042	5.40	4.60	0.90	3.90	5.40
10.0	305.5	200.1	-47.	-154.	0.	4.82	5.10	0.	-0.00045	5.80	4.70	1.20	4.00	6.20
10.0	311.0	207.6	-46.	-162.	0.	5.07	5.32	0.	-0.00047	6.20	4.70	1.00	4.20	6.50
11.0	315.4	213.4	-45.	-169.	0.	5.29	5.51	0.	-0.00049	6.20	4.80	1.10	4.40	6.00
11.0	318.6	217.4	-43.	-174.	0.	5.48	5.67	0.	-0.00051	7.40	4.70	1.50	4.50	6.[illegible]
11.0	320.4	219.8	-41.	-179.	0.	5.64	5.79	0.	-0.00052	7.70	4.70	1.90	4.60	[illegible]

Model Output 20-03-80 Actuals





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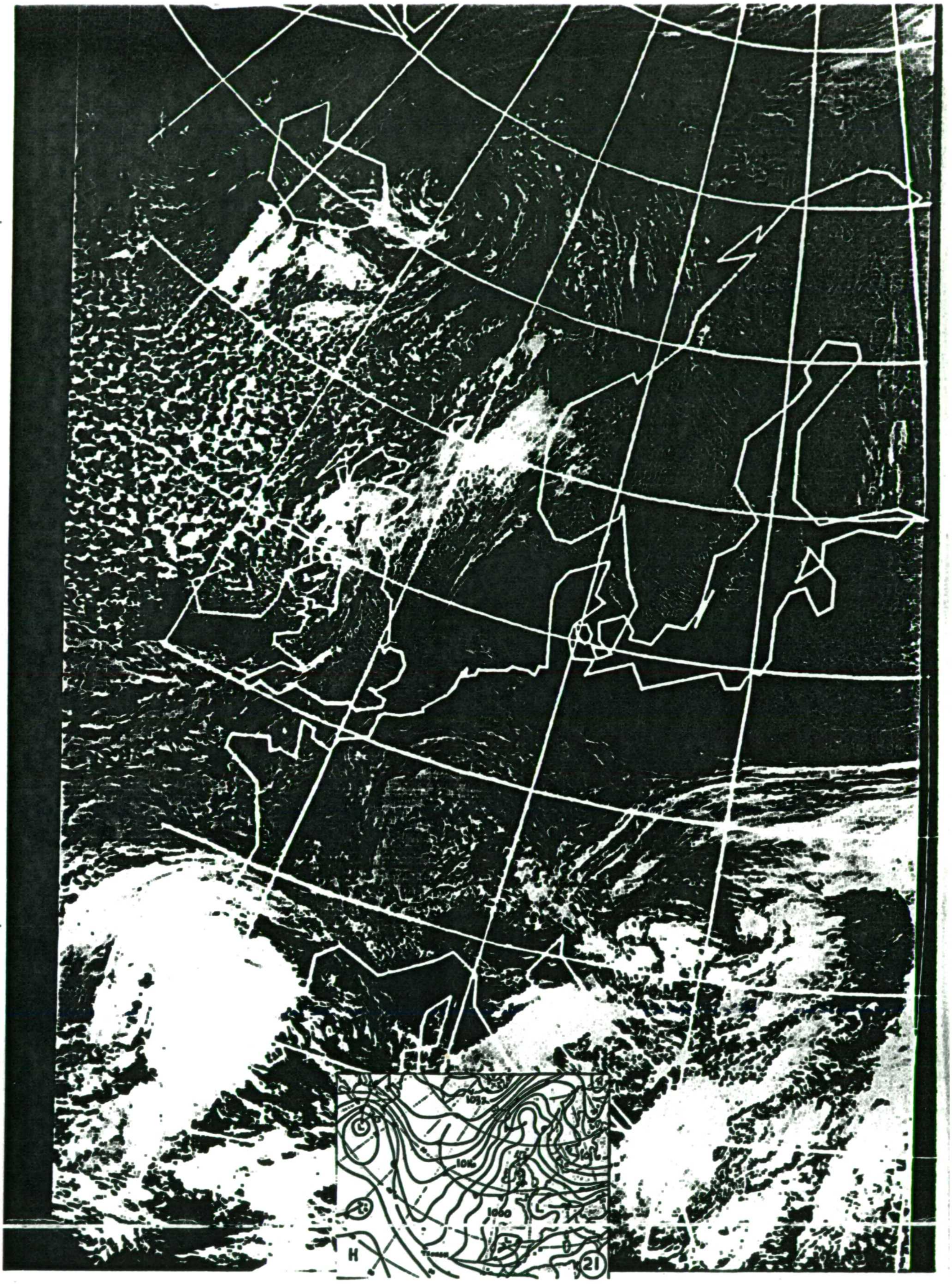


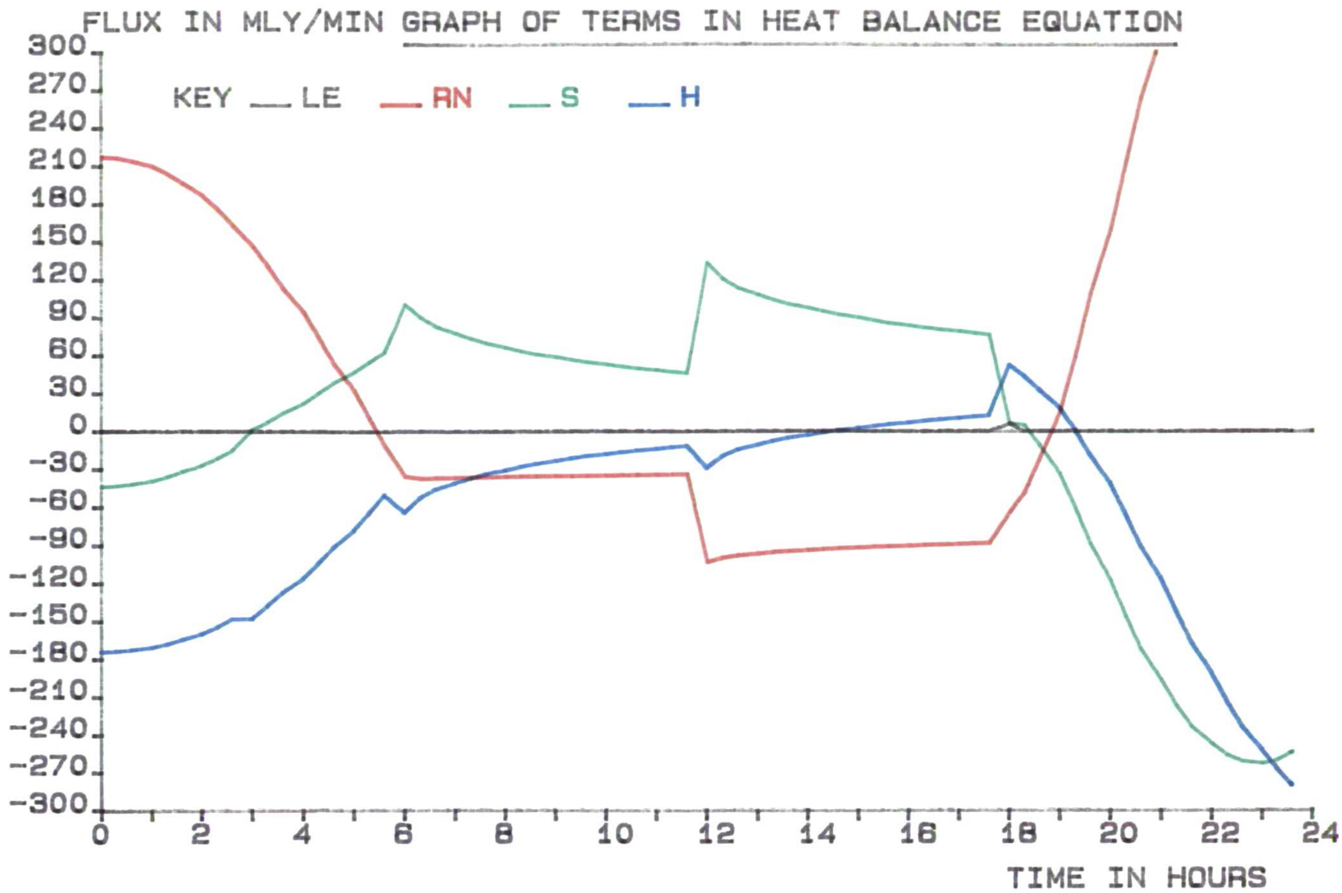
21-03-80

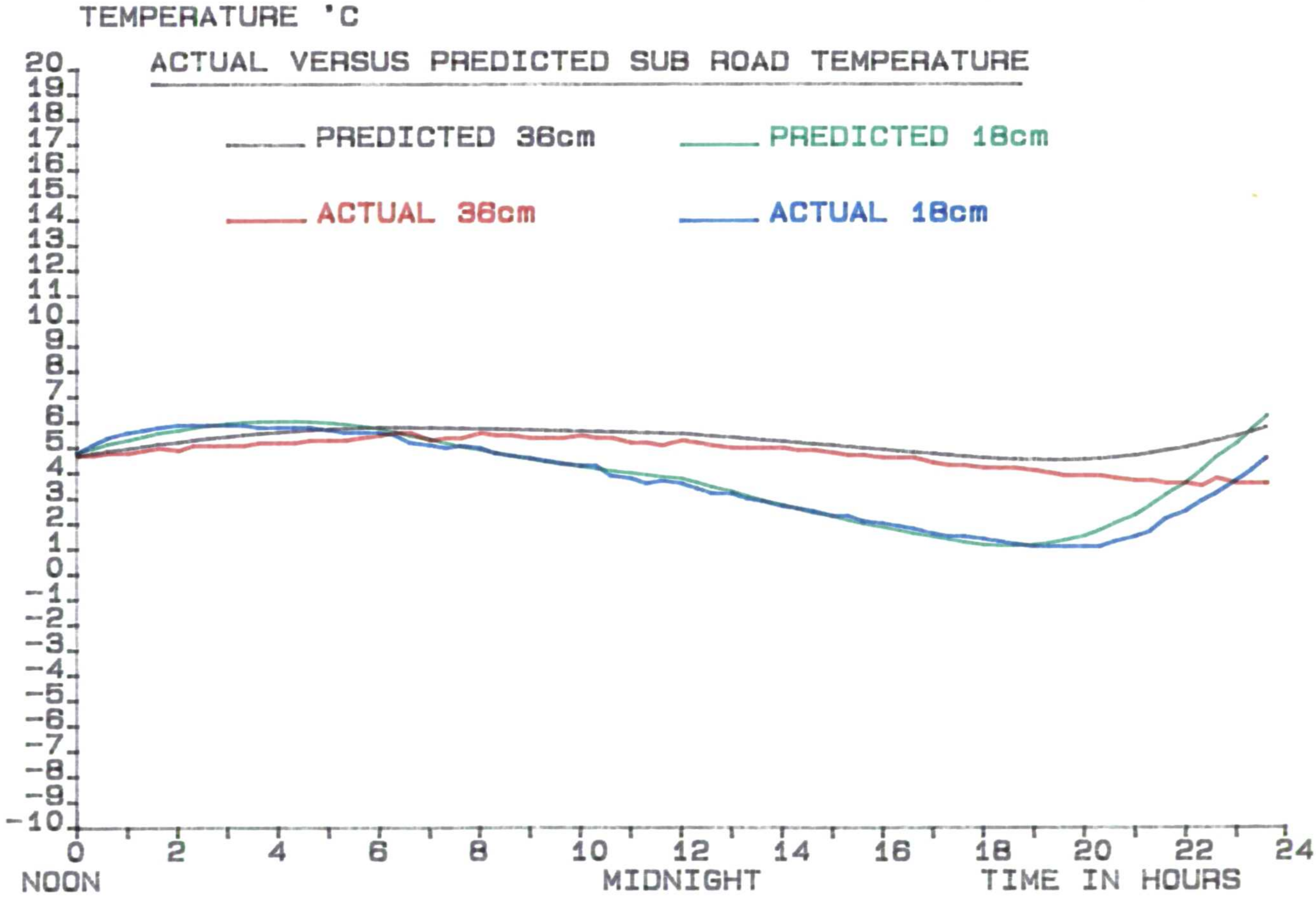
COMPUTED DATA
SAT. VAP. PRESSURE(MB)= 7.16
VAPOUR PRESSURE(MB)= 5.44
REL. HUMIDITY FRACTION = 0.76
APPROX. PRECIP. WATER(MM)= 8.8
ROAD DAMPING DEPTH(CM)= 72.
AIR DAMPING DEPTH(CM)= 2163. 1560.
AIR HEAT TRANSFER COEF.(CGS)= 0.00181 0.00101

DEC	R	T36	T18	TS	UA	D	TIME WET
0.790	0.997	277.9	278.0	9.5	280. 136.	0.5	0

SOLAR TIME	SUN	RN	S (ALL MLY./MIN.)	H	LE	TD	TC (C.)	SUM	RI	TO	T36	Air	T18	Tsla
12.0	320.3	217.1	-44.	-174.	0.	9.50	9.03	1.	-0.00147	9.50	4.70	2.40	4.80	11.80
12.0	319.7	216.3	-43.	-173.	0.	9.26	9.02	0.	-0.00147	10.30	4.70	2.80	5.10	12.70
12.0	317.8	213.7	-42.	-172.	0.	9.12	8.98	0.	-0.00146	9.40	4.80	2.70	5.40	11.20
13.0	314.7	209.6	-39.	-171.	0.	9.01	8.91	0.	-0.00145	8.50	4.80	1.90	5.60	9.90
13.0	310.4	203.7	-36.	-168.	0.	8.91	8.81	0.	-0.00143	7.90	4.90	2.20	5.70	9.50
13.0	304.9	196.0	-32.	-164.	0.	8.79	8.68	0.	-0.00140	7.40	5.00	1.90	5.80	8.70
14.0	298.2	186.8	-27.	-160.	0.	8.65	8.51	0.	-0.00136	7.20	4.90	2.20	5.90	8.60
14.0	290.3	175.7	-21.	-155.	0.	8.48	8.31	0.	-0.00131	6.90	5.10	2.10	5.90	8.00
14.0	281.2	162.9	-15.	-148.	0.	8.27	8.06	0.	-0.00126	6.80	5.10	2.00	5.90	7.70
15.0	272.1	146.4	1.	-148.	0.	7.91	7.55	0.	-0.00126	6.80	5.10	2.00	5.90	7.70
15.0	260.7	130.4	7.	-138.	0.	7.54	7.17	0.	-0.00118	6.60	5.10	1.90	5.90	7.30
15.0	248.1	112.9	14.	-128.	0.	7.16	6.78	0.	-0.00109	6.50	5.20	2.00	5.80	7.10
16.0	234.2	94.1	22.	-116.	0.	6.76	6.36	0.	-0.00100	6.00	5.20	1.70	5.80	6.60
16.0	218.8	74.1	30.	-105.	0.	6.33	5.91	0.	-0.00090	5.60	5.20	1.60	5.60	6.20
16.0	201.5	53.2	38.	-92.	0.	5.88	5.42	0.	-0.00079	5.40	5.30	1.60	5.80	5.90
17.0	181.3	31.7	47.	-79.	0.	5.40	4.92	0.	-0.00068	5.10	5.30	1.70	5.70	5.60
17.0	155.8	9.8	55.	-65.	0.	4.90	4.39	0.	-0.00056	5.00	5.30	1.70	5.60	5.40
17.0	116.7	-12.2	62.	-51.	0.	4.38	3.85	0.	-0.00044	4.70	5.40	1.50	5.60	4.90
18.0	20.1	-36.2	100.	-64.	0.	3.47	2.57	0.	-0.00056	4.40	5.50	1.50	5.60	4.40
18.0	0.0	-37.6	90.	-53.	0.	2.80	2.13	0.	-0.00046	4.20	5.60	1.30	5.50	3.90
18.0	0.0	-37.1	83.	-46.	0.	2.34	1.87	0.	-0.00040	4.00	5.60	1.30	5.20	3.60
19.0	0.0	-36.7	77.	-41.	0.	2.01	1.68	0.	-0.00036	3.50	5.30	0.80	5.10	2.90
19.0	0.0	-36.4	73.	-37.	0.	1.77	1.53	0.	-0.00032	3.10	5.40	0.50	5.00	2.40
19.0	0.0	-36.2	69.	-34.	0.	1.59	1.40	0.	-0.00029	3.00	5.40	0.20	5.10	2.10
20.0	0.0	-35.9	66.	-31.	0.	1.44	1.29	0.	-0.00027	2.90	5.60	0.50	5.00	1.90
20.0	0.0	-35.7	63.	-28.	0.	1.31	1.19	0.	-0.00024	2.70	5.50	0.30	4.80	1.90
20.0	0.0	-35.5	61.	-26.	0.	1.21	1.10	0.	-0.00022	2.60	5.50	0.20	4.70	1.80
21.0	0.0	-35.4	58.	-23.	0.	1.11	1.01	0.	-0.00020	2.20	5.40	0.00	4.60	1.30
										1.60	5.40	-0.10	4.50	0.80
21.0	0.0	-35.2	56.	-21.	0.	1.02	0.94	0.	-0.00019	1.60	5.40	-0.50	4.40	0.60
21.0	0.0	-35.1	54.	-20.	0.	0.95	0.87	0.	-0.00017	1.30	5.50	-0.80	4.30	0.10
22.0	0.0	-34.9	53.	-18.	0.	0.88	0.81	0.	-0.00016	1.00	5.40	-0.80	4.30	-0.10
22.0	0.0	-34.8	51.	-17.	0.	0.81	0.75	0.	-0.00014	0.70	5.40	-0.90	3.90	-0.50
22.0	0.0	-34.7	49.	-15.	0.	0.75	0.70	0.	-0.00013	0.30	5.20	-1.50	3.80	-1.00
23.0	0.0	-34.6	48.	-14.	0.	0.70	0.65	0.	-0.00012	0.10	5.20	-1.90	3.60	-1.20
23.0	0.0	-34.5	47.	-13.	0.	0.65	0.60	0.	-0.00011	-0.20	5.10	-1.80	3.70	-1.50
23.0	0.0	-34.4	46.	-12.	0.	0.60	0.56	0.	-0.00010	-0.30	5.30	-2.40	3.60	-1.70
0.0	0.0	-103.6	133.	-29.	0.	-0.51	-1.63	0.	-0.00183	-0.50	5.20	-2.10	3.40	-1.90
0.0	0.0	-100.2	120.	-20.	0.	-1.39	-2.27	0.	-0.00126	-0.60	5.10	-2.30	3.20	-2.00
0.0	0.0	-98.2	113.	-15.	0.	-2.01	-2.64	0.	-0.00092	-0.80	5.00	-2.40	3.20	-2.10
1.0	0.0	-96.8	108.	-11.	0.	-2.45	-2.89	0.	-0.00068	-1.00	5.00	-2.80	3.00	-2.40
1.0	0.0	-95.8	104.	-8.	0.	-2.78	-3.10	0.	-0.00050	-1.20	5.00	-2.90	2.90	-2.50
1.0	0.0	-94.8	100.	-5.	0.	-3.02	-3.27	0.	-0.00034	-1.30	5.00	-3.50	2.70	-2.80
2.0	0.0	-94.0	97.	-3.	0.	-3.22	-3.42	0.	-0.00020	-1.50	4.90	-4.10	2.60	-3.00
2.0	0.0	-93.3	95.	-1.	0.	-3.39	-3.56	0.	-0.00007	-1.70	4.90	-4.10	2.50	-3.10
2.0	0.0	-92.6	92.	1.	0.	-3.54	-3.69	0.	0.00004	-1.80	4.80	-4.00	2.30	-3.40
3.0	0.0	-92.0	90.	2.	0.	-3.67	-3.81	0.	0.00015	-2.00	4.70	-4.60	2.30	-3.50
3.0	0.0	-91.4	88.	4.	0.	-3.80	-3.92	0.	0.00025	-2.10	4.70	-4.70	2.10	-3.60
3.0	0.0	-90.9	86.	5.	0.	-3.91	-4.02	0.	0.00034	-2.20	4.60	-4.40	2.00	-3.70
4.0	0.0	-90.4	84.	7.	0.	-4.01	-4.11	0.	0.00043	-2.30	4.60	-4.60	1.90	-3.90
4.0	0.0	-89.9	82.	8.	0.	-4.11	-4.20	0.	0.00051	-2.40	4.60	-4.30	1.80	-4.00
4.0	0.0	-89.5	80.	9.	0.	-4.20	-4.29	0.	0.00059	-2.60	4.40	-5.10	1.60	-4.30
5.0	0.0	-89.1	79.	10.	0.	-4.28	-4.36	0.	0.00066	-2.70	[illegible]	-4.80	1.50	-4.30
5.0	0.0	-88.7	77.	11.	0.	-4.36	-4.44	0.	0.00073	-2.80	4.30	-5.10	1.50	-4.40
5.0	0.0	-88.3	76.	12.	0.	-4.43	-4.51	0.	0.00079	-2.80	4.20	-4.90	1.40	-4.50
6.0	16.6	-64.1	6.	52.	6.	-3.67	-2.90	6.	0.00331	-2.80	4.20	-5.50	1.30	-4.60
6.0	92.9	-48.5	5.	44.	0.	-2.97	-2.28	6.	0.00274	-2.70	4.20	-4.70	1.20	-4.50
6.0	163.3	-21.6	-11.	33.	0.	-2.24	-1.51	6.	0.00204	-2.20	4.10	-3.80	1.10	-4.00
7.0	234.5	15.1	-34.	19.	0.	-1.39	-0.53	6.	0.00116	-1.50	4.00	-3.00	1.10	-3.20
7.0	305.1	58.8	-60.	1.	0.	-0.36	0.66	6.	0.00009					
7.0	374.6	107.5	-89.	-19.	0.	0.84	2.03	6.	-0.00115					
8.0	442.3	159.3	-118.	-41.	0.	2.20	3.56	6.	-0.00251	-0.70	3.90	-2.20	1.10	-2.00
8.0	507.1	211.8	-146.	-65.	0.	3.69	5.18	6.	-0.00394	0.20	3.90	-1.70	1.10	-0.60
8.0	568.6	263.5	-173.	-91.	0.	5.27	6.86	6.	-0.00542	1.30	3.90	-0.60	1.10	1.10
9.0	626.4	313.4	-197.	-117.	0.	6.91	8.55	6.	-0.00691	2.50	3.80	0.10	1.30	2.90
9.0	679.5	359.7	-217.	-142.	0.	8.56	10.22	6.	-0.00836	3.70	3.70	1.60	1.50	4.60
9.0	727.6	401.8	-234.	-167.	0.	10.19	11.82	6.	-0.00975	5.20	3.70	2.70	1.70	6.70
10.0	770.5	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	6.	-0.01106	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
10.0	807.3	470.5	-257.	-214.	0.	13.26	14.75	6.	-0.01226	8.00	3.60	4.50	2.50	10.10
10.0	837.9	496.0	-262.	-234.	0.	14.64	16.02	6.	-0.01335	9.40	3.50	4.90	2.90	12.00
11.0	862.3	515.5	-263.	-252.	0.	15.90	17.15	6.	-0.01430	10.50	3.80	4.60	3.20	13.50
11.0	879.7	528.4	-261.	-268.	0.	17.00	18.11	6.	-0.01511	10.90	3.60	4.90	3.70	13.50
11.0	890.2	534.7	-254.	-280.	0.	17.95	18.89	6.	-0.01577	10.90	3.60	4.80	4.10	13.30
										12.50	3.60	5.50	4.60	12.60

Model Output 21-03-80 Actuals





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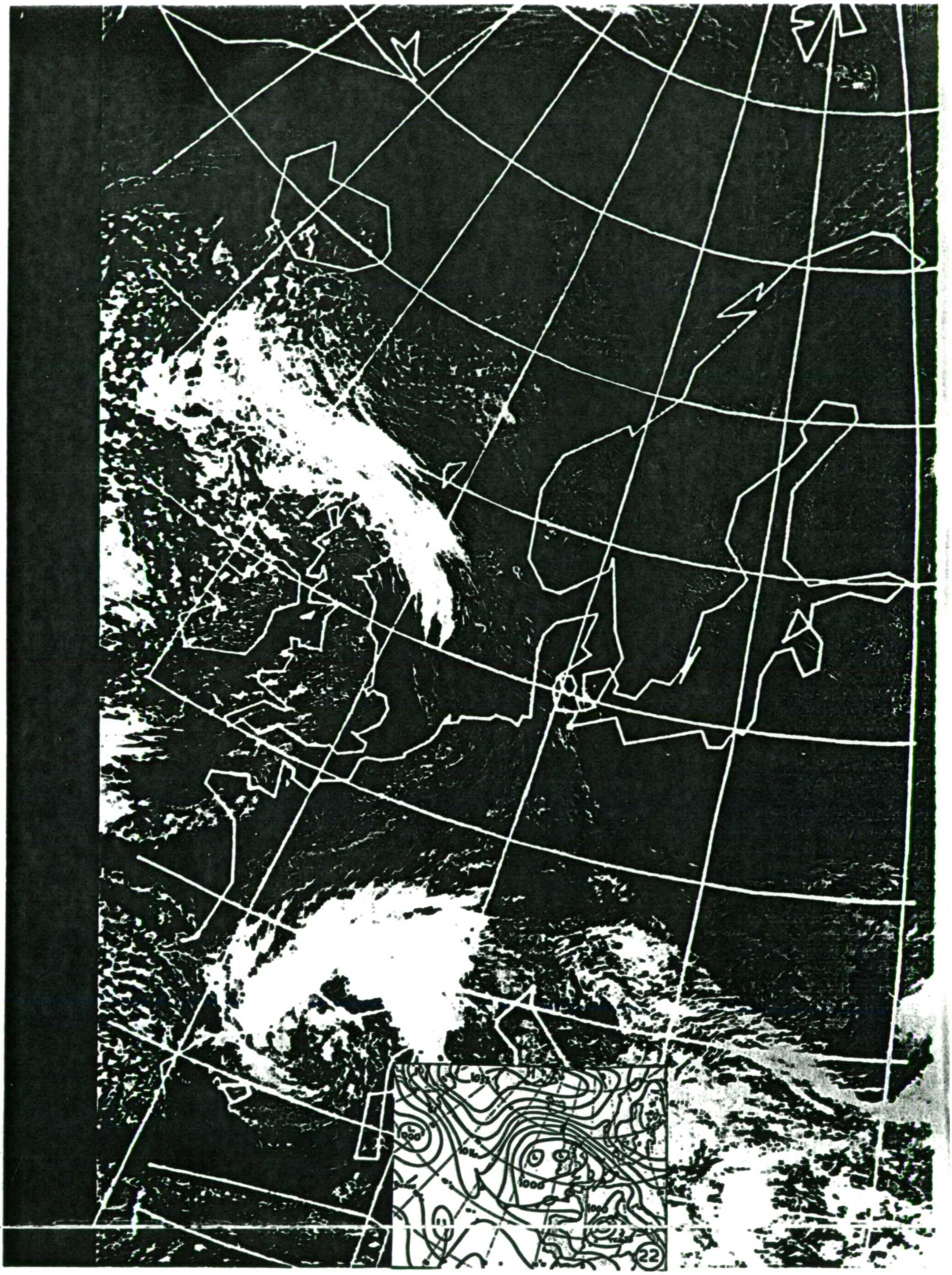


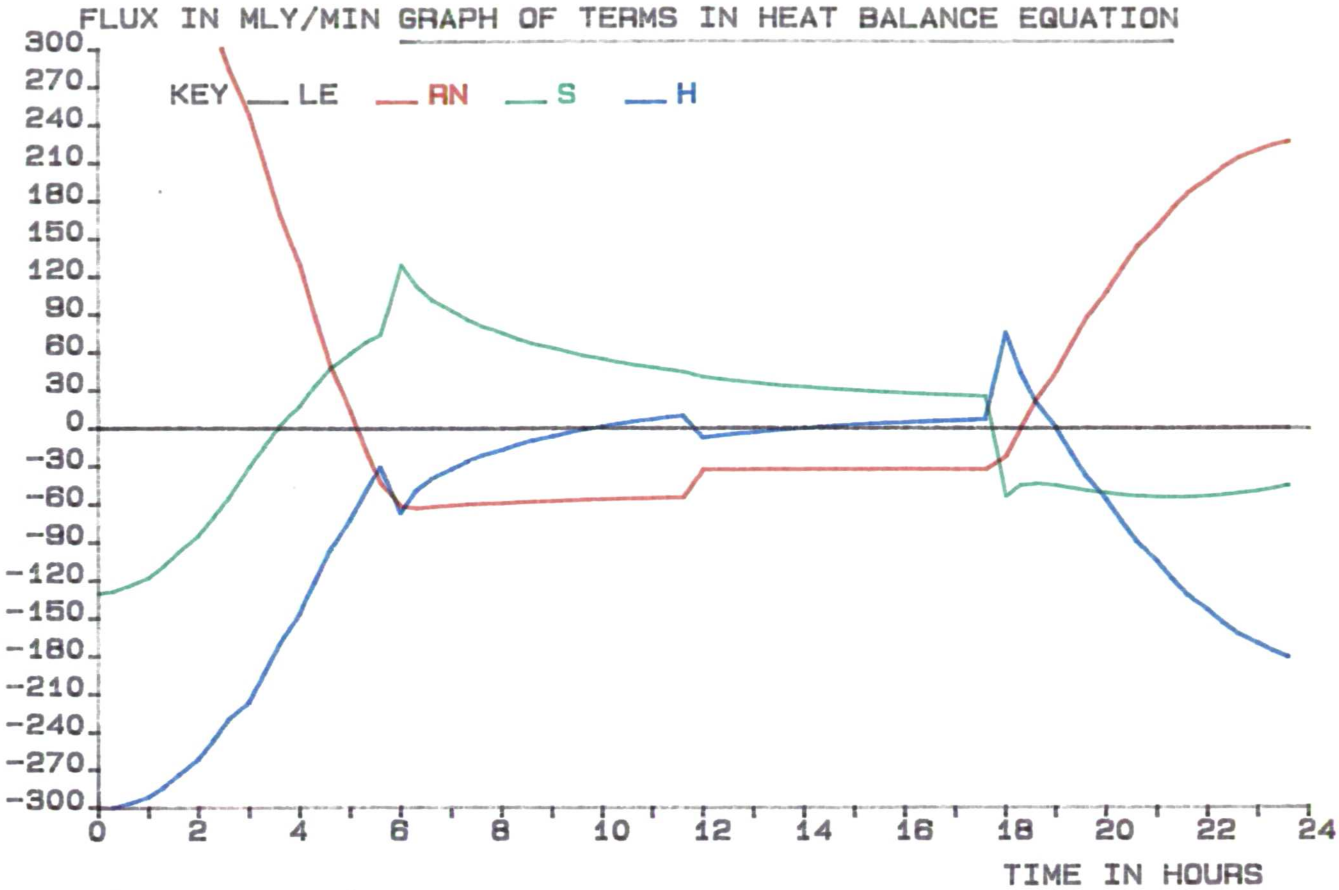
22-03-80

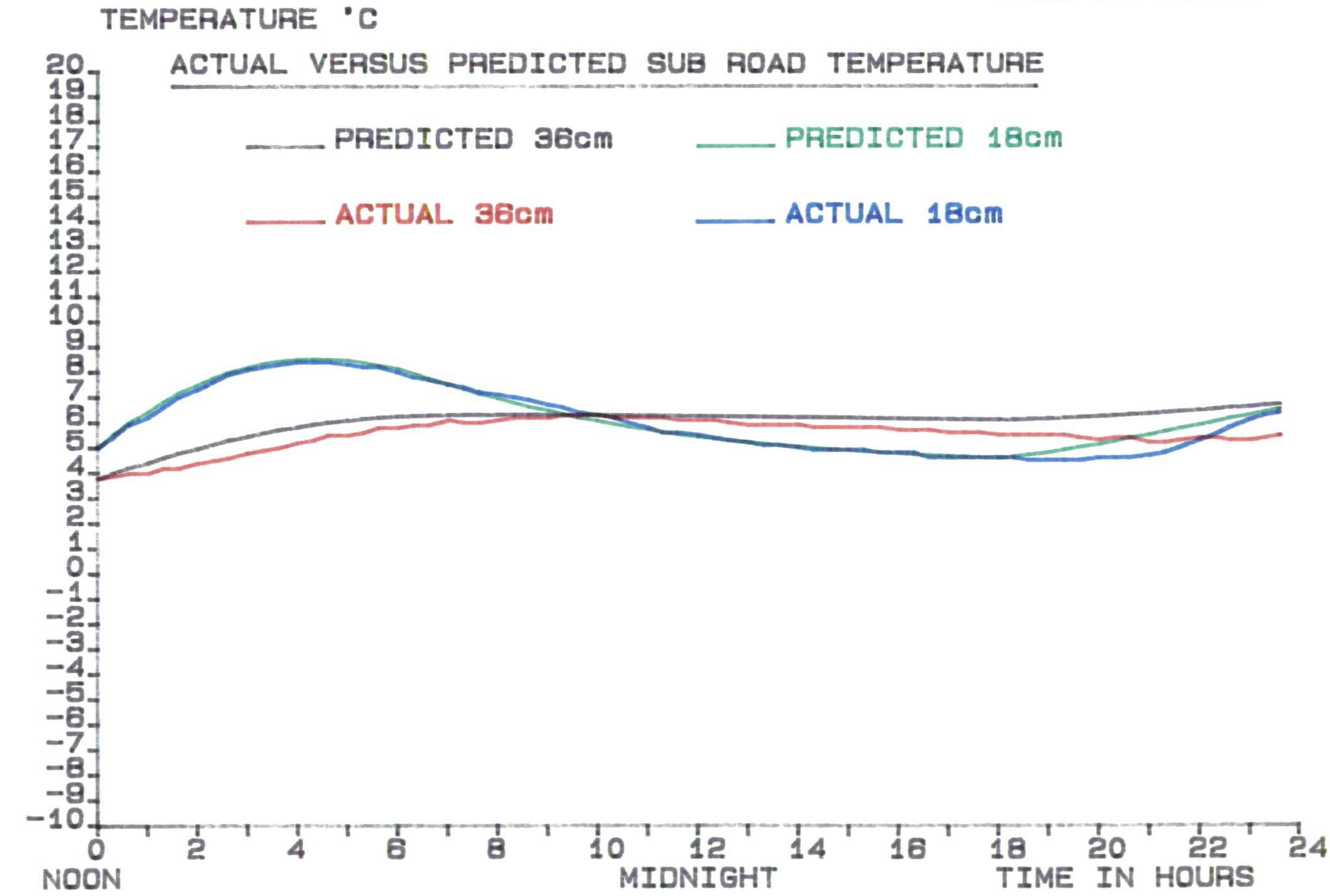
[illegible]
SAT. VAP. PRESSURE(MB)= 9.67
VAPOUR PRESSURE(MB)= 4.93
REL. HUMIDITY FRACTION = 0.51
APPROX. PRECIP. WATER(MM)= 8.0
ROAD DAMPING DEPTH(CM)= 72.
AIR DAMPING DEPTH(CM)= 2221. 3324.
AIR HEAT TRANSFER COEF.(CGS)= 0.00190 0.00394

DEC	R	T36	T18	TS	UA	D	TIME WET
1.184	0.997	277.0	278.2	13.1	297. 719.	0.5	0

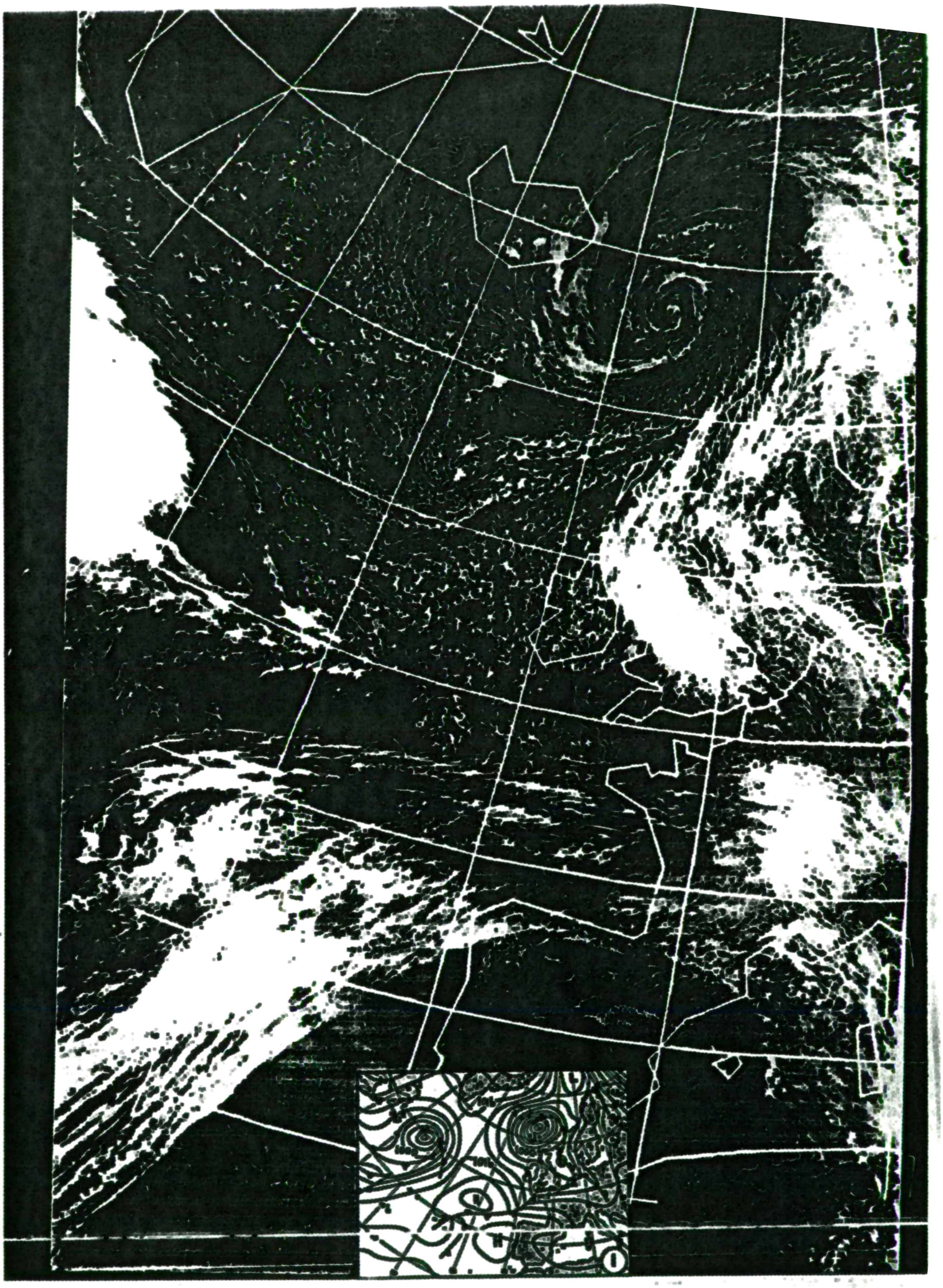
SOLAR TIME	SUN	RN	S	H	LE	TD	TC (C.)	SUM	RI	TO	T36	Air	T18	Tslab
			(ALL MLY./MIN.)											
12.0	656.1	431.3	-130.	-301.	0.	13.10	17.61	1.	-0.00212	13.10	3.80	5.20	5.00	14.2
12.0	653.8	428.8	-129.	-300.	0.	15.34	17.57	0.	-0.00211	13.20	3.90	6.40	5.40	15.5
12.0	647.0	421.5	-125.	-297.	0.	16.40	17.46	0.	-0.00209	14.60	4.00	5.70	5.90	17.3
13.0	635.9	409.7	-118.	-292.	0.	16.83	17.27	0.	-0.00205	14.70	4.00	6.30	6.20	[illegible]
13.0	620.2	393.0	-109.	-284.	0.	16.92	17.00	0.	-0.00200	14.40	4.20	6.70	6.60	[illegible]
13.0	600.3	371.8	-98.	-274.	0.	16.78	16.64	0.	-0.00193	15.90	4.20	6.60	7.00	[illegible]
14.0	576.5	346.5	-85.	-262.	0.	16.49	16.20	0.	-0.00185	15.80	4.40	7.40	7.30	18.3
14.0	548.6	317.1	-70.	-247.	0.	16.08	15.67	0.	-0.00175	13.50	4.50	6.80	7.60	[illegible]
14.0	517.1	284.1	-54.	-230.	0.	15.56	15.05	0.	-0.00163	14.70	4.60	7.50	7.90	[illegible]
15.0	484.4	247.4	-31.	-217.	0.	14.87	14.18	0.	-0.00154	13.50	4.80	6.50	8.10	[illegible]
15.0	446.3	209.1	-15.	-194.	0.	14.12	13.37	0.	-0.00138	13.00	4.90	6.70	8.20	14.1
15.0	405.5	169.0	2.	-171.	0.	13.32	12.52	0.	-0.00122	13.20	5.00	6.80	8.30	[illegible]
16.0	362.4	128.5	18.	-146.	0.	12.48	11.64	0.	-0.00105	11.60	5.20	6.60	8.40	[illegible]
16.0	316.9	88.1	33.	-122.	0.	11.61	10.74	0.	-0.00087	10.80	5.30	6.50	8.40	[illegible]
16.0	269.4	49.4	47.	-97.	0.	10.73	9.84	0.	-0.00070	10.40	5.50	6.40	8.40	[illegible]
17.0	220.1	13.7	59.	-73.	0.	9.85	8.98	0.	-0.00053	10.10	5.50	5.90	8.30	[illegible]
17.0	168.1	-17.8	68.	-51.	0.	9.01	8.17	0.	-0.00037	9.30	5.60	5.10	8.20	[illegible]
17.0	110.7	-43.6	74.	-31.	0.	8.23	7.44	0.	-0.00022	8.30	5.80	4.50	8.20	[illegible]
18.0	28.1	-62.2	129.	-67.	0.	6.90	5.57	0.	-0.00049	7.80	5.80	4.40	8.00	[illegible]
18.0	0.0	-63.3	112.	-50.	0.	5.92	4.94	0.	-0.00036	7.40	5.90	4.50	7.80	[illegible]
18.0	0.0	-61.9	101.	-40.	0.	5.24	4.57	0.	-0.00029	7.10	5.90	4.50	7.70	[illegible]
19.0	0.0	-60.9	93.	-32.	0.	4.77	4.30	0.	-0.00024	7.00	6.10	4.30	7.50	[illegible]
19.0	0.0	-60.1	86.	-26.	0.	4.43	4.09	0.	-0.00019	6.50	6.00	4.20	7.40	[illegible]
19.0	0.0	-59.4	80.	-22.	0.	4.17	3.91	0.	-0.00016	6.20	6.00	4.00	7.20	[illegible]
20.0	0.0	-58.7	75.	-17.	0.	3.96	3.75	0.	-0.00013	5.90	6.10	3.90	7.10	[illegible]
20.0	0.0	-58.2	71.	-13.	0.	3.78	3.61	0.	-0.00010	5.60	6.20	3.50	7.00	[illegible]
20.0	0.0	-57.7	67.	-10.	0.	3.63	3.48	0.	-0.00007	5.20	6.20	3.10	6.90	[illegible]
21.0	0.0	-57.3	63.	-7.	0.	3.50	3.36	0.	-0.00005	4.90	6.20	2.90	6.70	[illegible]
										4.50	6.30	2.10	6.60	[illegible]
21.0	0.0	-56.9	60.	-4.	0.	3.38	3.26	0.	-0.00003	4.10	6.30	2.40	6.40	[illegible]
21.0	0.0	-56.5	57.	-1.	0.	3.27	3.17	0.	-0.00001	3.80	6.30	1.20	6.30	3.1
22.0	0.0	-56.2	54.	1.	0.	3.18	3.08	0.	0.00001	3.50	6.20	1.30	6.20	[illegible]
22.0	0.0	-55.9	52.	3.	0.	3.09	3.00	0.	0.00002	3.40	6.20	1.30	6.00	[illegible]
22.0	0.0	-55.7	50.	5.	0.	3.01	2.93	0.	0.00004	3.40	6.20	1.20	5.80	[illegible]
23.0	0.0	-55.4	48.	7.	0.	2.94	2.87	0.	0.00005	3.60	6.20	1.40	5.60	3.1
23.0	0.0	-55.2	46.	9.	0.	2.87	2.81	0.	0.00006	3.60	6.10	1.60	5.60	3.2
23.0	0.0	-55.0	44.	10.	0.	2.81	2.75	0.	0.00007	3.50	6.10	1.60	5.50	3.1
0.0	0.0	-33.0	40.	-8.	0.	2.79	2.76	0.	0.00000	3.60	6.10	2.10	5.40	3.1
0.0	0.0	-33.0	39.	-6.	0.	2.77	2.74	0.	0.00000	3.50	6.00	2.20	5.30	[illegible]
0.0	0.0	-32.9	37.	-5.	0.	2.74	2.72	0.	0.00000	3.50	5.90	2.10	5.20	[illegible]
1.0	0.0	-32.9	36.	-3.	0.	2.72	2.69	0.	0.00000	3.30	5.90	2.20	5.10	[illegible]
1.0	0.0	-32.8	35.	-2.	0.	2.70	2.67	0.	0.00000	3.40	5.90	2.00	5.10	[illegible]
1.0	0.0	-32.8	33.	-1.	0.	2.67	2.65	0.	0.00000	3.40	5.90	2.10	5.00	2.80
2.0	0.0	-32.8	32.	0.	0.	2.65	2.63	0.	0.00000	3.40	5.80	2.20	4.90	2.80
2.0	0.0	-32.7	31.	1.	0.	2.64	2.62	0.	0.00000	3.30	5.80	2.30	4.90	2.80
2.0	0.0	-32.7	30.	2.	0.	2.62	2.60	0.	0.00000	3.40	5.80	2.50	4.90	2.80
3.0	0.0	-32.7	30.	2.	0.	2.60	2.59	0.	0.00000	3.20	5.80	2.60	4.90	2.50
3.0	0.0	-32.6	29.	3.	0.	2.59	2.58	0.	0.00000	3.00	5.80	2.30	4.80	2.40
3.0	0.0	-32.6	28.	4.	0.	2.58	2.56	0.	0.00000	3.10	5.70	2.20	4.80	2.50
4.0	0.0	-32.6	27.	5.	0.	2.56	2.55	0.	0.00000	3.20	5.70	2.40	4.80	2.70
4.0	0.0	-32.6	27.	5.	0.	2.55	2.54	0.	0.00000	3.20	5.70	2.50	4.60	2.70
4.0	0.0	-32.6	26.	6.	0.	2.54	2.53	0.	0.00000	3.00	5.60	2.60	4.60	2.40
5.0	0.0	-32.5	26.	6.	0.	2.53	2.52	0.	0.00000	3.00	5.60	2.70	4.60	2.50
5.0	0.0	-32.5	25.	7.	0.	2.52	2.52	0.	0.00000	3.20	5.60	3.10	4.60	[illegible]
5.0	0.0	-32.5	25.	7.	0.	2.52	2.51	0.	0.00000	3.40	5.50	3.60	4.60	[illegible]
6.0	42.2	-22.2	-54.	76.	0.	3.46	4.40	0.	0.00005	3.20	5.50	3.40	4.60	2.50
6.0	123.8	0.2	-45.	44.	0.	4.21	4.95	0.	0.00003	3.30	5.50	3.60	4.50	2.70
6.0	159.3	22.3	-44.	21.	0.	4.78	5.36	0.	0.00001	3.60	5.50	3.70	4.50	3.10
7.0	183.5	44.4	-46.	1.	0.	5.25	5.72	0.	0.00000	3.80	5.50	3.70	4.50	3.20
7.0	203.0	66.0	-48.	-19.	0.	5.66	6.07	0.	-0.00001					
7.0	219.8	87.1	-50.	-38.	0.	6.03	6.40	0.	-0.00002	4.30	5.40	4.20	4.50	4.10
8.0	234.9	107.2	-52.	-56.	0.	6.38	6.72	0.	-0.00004	5.00	5.30	4.60	4.60	4.80
8.0	248.6	126.1	-53.	-73.	0.	6.70	7.03	0.	-0.00005	5.10	5.40	4.50	4.60	[illegible]
8.0	260.9	143.6	-54.	-90.	0.	7.01	7.31	0.	-0.00006	5.40	5.40	4.90	4.60	5.10
9.0	272.2	159.6	-55.	-105.	0.	7.30	7.58	0.	-0.00007	6.30	5.20	5.30	4.70	[illegible]
9.0	282.3	174.0	-55.	-119.	0.	7.56	7.83	0.	-0.00008	7.10	5.20	5.80	4.80	6.90
9.0	291.3	186.6	-55.	-132.	0.	7.81	8.06	0.	-0.00009	8.40	5.30	6.20	5.00	[illegible]
10.0	[illegible]	[illegible]	[illegible]	[illegible]	0.	[illegible]	[illegible]	0.	-0.00009	9.60	5.40	6.80	5.30	[illegible]
10.0	305.8	206.8	-53.	-154.	0.	8.24	8.44	0.	-0.00010	10.70	5.40	7.00	5.50	11.50
10.0	311.3	214.3	-52.	-163.	0.	8.42	8.60	0.	-0.00010	9.80	5.30	6.70	5.80	[illegible]
11.0	315.7	220.1	-50.	-171.	0.	8.58	8.73	0.	-0.00011	10.70	5.30	7.60	6.10	11.30
11.0	318.7	224.2	-48.	-177.	0.	8.71	8.84	0.	-0.00011	11.10	5.40	7.30	6.30	[illegible]
11.0	320.6	226.6	-46.	-181.	0.	8.82	8.93	0.	-0.00012	12.10	5.50	8.10	6.40	[illegible]

Model Output 22-03-80 Actuals





22-23 MARCH 1980



01-04-80

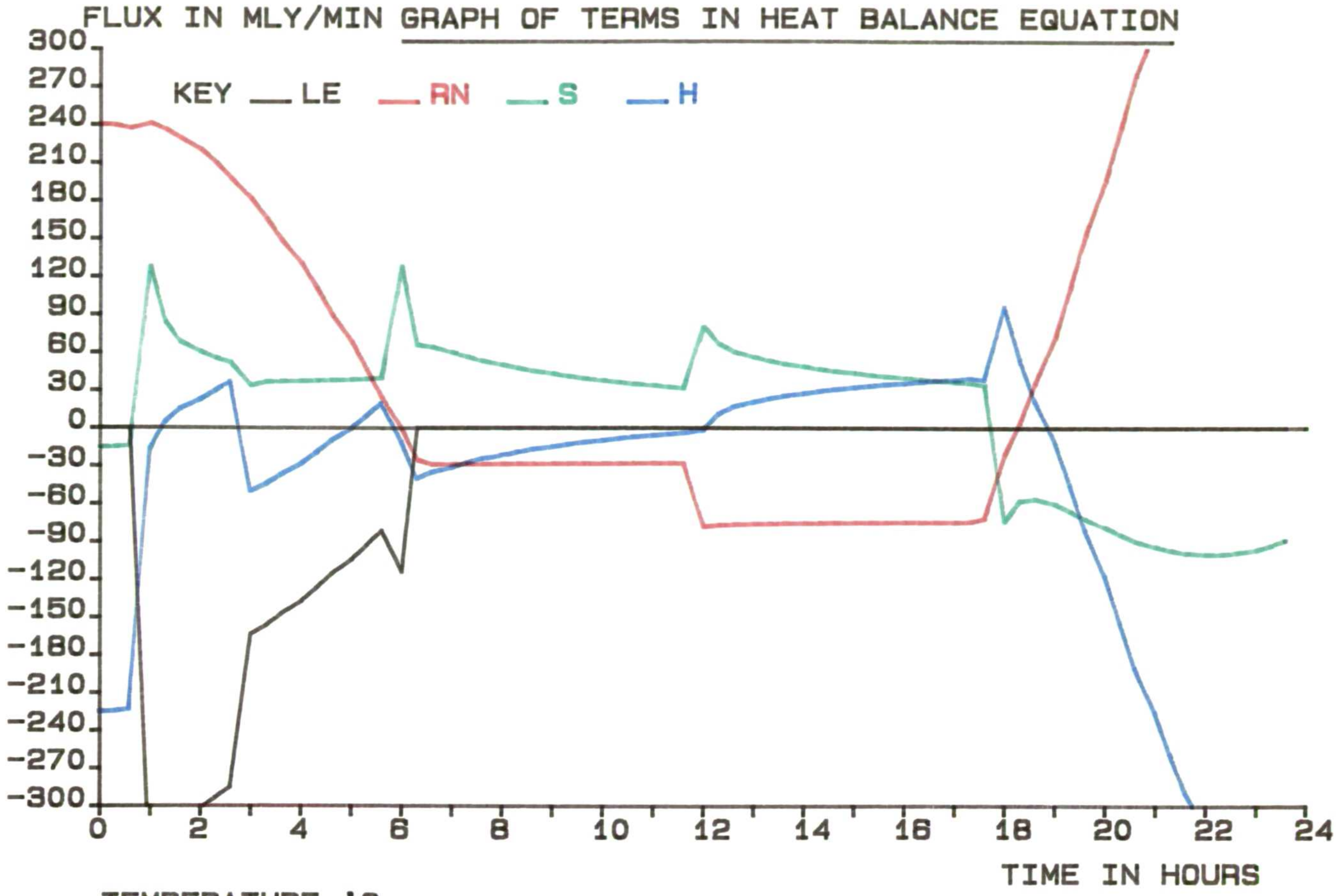
COMPUTED DATA
SAT. VAP. PRESSURE(MB)= 12.03
VAPOUR PRESSURE(MB)= 8.66
REL. HUMIDITY FRACTION = 0.72
APPROX. PRECIP. WATER(MM)= 13.6
ROAD DAMPING DEPTH(CM)= 72.
AIR DAMPING DEPTH(CM)= 3420. 3544.
AIR HEAT TRANSFER COEF.(CGS)= 0.00415 0.00443

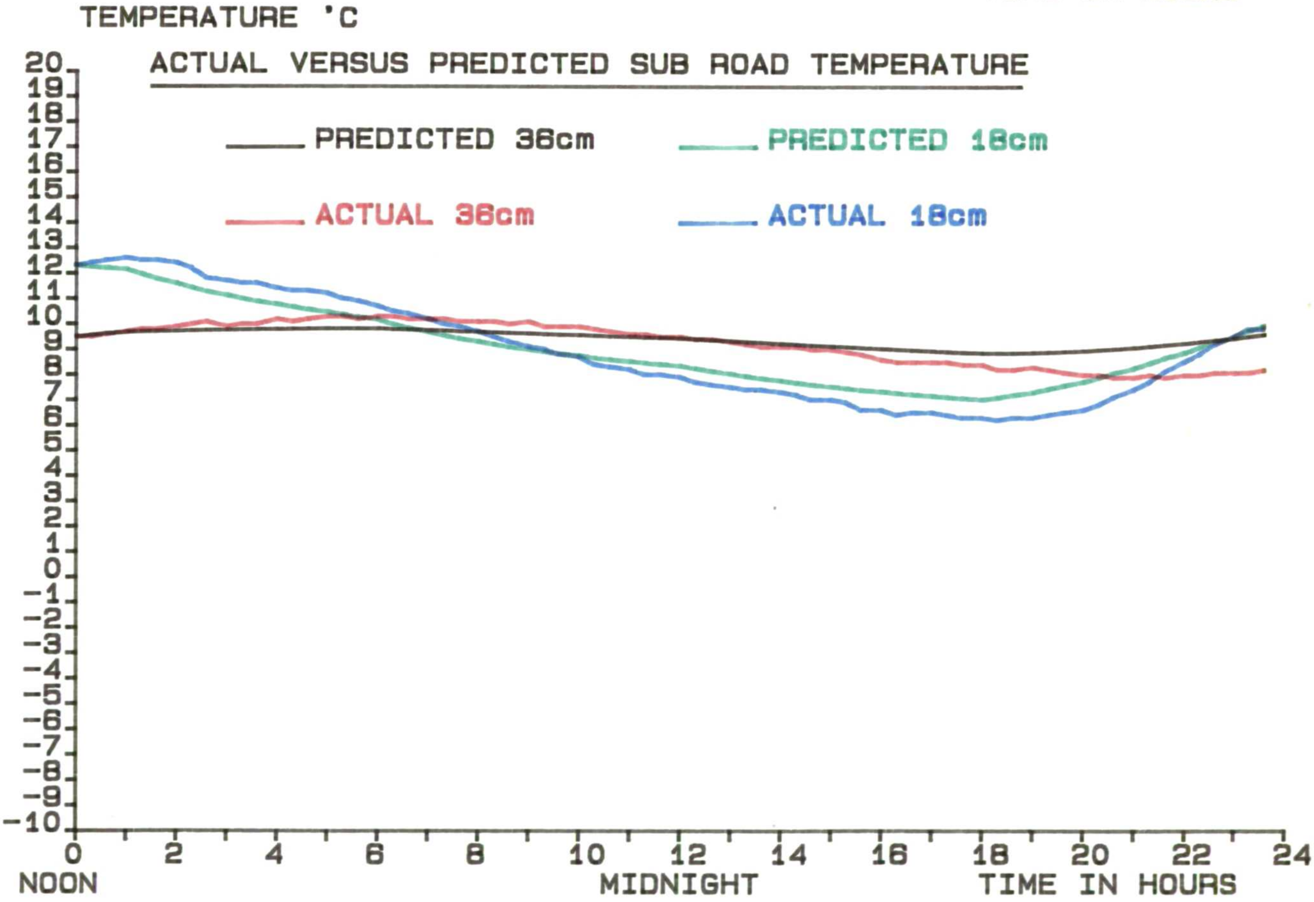
DEC	R	T36	T18	TS	UA	D	TIME WET
5.082	1.000	282.7	285.5	12.8	765. 827.	0.5	13

SOLAR TIME	SUN	NN	S	H	LE	TD	TC (C.)	SUM	RI
			(ALL MLY./MIN.)						
12.0	328.7	240.0	-16.	-225.	0.	12.80	13.81	1.	-0.00012
12.0	328.1	239.3	-15.	-225.	0.	13.30	13.80	0.	-0.00012
12.0	326.3	236.9	-14.	-223.	0.	13.54	13.77	0.	-0.00012
13.0	323.4	240.8	127.	-17.	-351.	11.93	10.33	-351.	-0.00001
13.0	319.2	235.9	84.	4.	-324.	10.95	9.97	-674.	0.00000
13.0	313.9	228.8	68.	15.	-311.	10.37	9.80	-985.	0.00001
14.0	307.4	220.1	60.	22.	-302.	10.02	9.67	-1287.	0.00001
14.0	299.8	209.5	55.	29.	-293.	9.79	9.56	-1581.	0.00002
14.0	291.2	197.2	51.	36.	-285.	9.61	9.44	-1866.	0.00002
15.0	280.1	181.1	33.	-51.	-164.	9.65	9.69	-2029.	-0.00003
15.0	269.4	165.5	36.	-45.	-157.	9.62	9.59	-2186.	-0.00002
15.0	257.7	148.4	37.	-37.	-148.	9.54	9.47	-2334.	-0.00002
16.0	245.0	130.0	37.	-29.	-138.	9.44	9.33	-2471.	-0.00002
16.0	231.1	110.3	37.	-20.	-127.	9.31	9.18	-2598.	-0.00001
16.0	215.8	89.5	37.	-11.	-116.	9.16	9.02	-2714.	-0.00001
17.0	198.9	68.0	38.	-1.	-105.	9.01	8.86	-2819.	0.00000
17.0	179.4	45.9	39.	9.	-93.	8.85	8.69	-2912.	0.00000
17.0	155.0	23.7	39.	19.	-82.	8.69	8.52	-2994.	0.00001
18.0	118.8	-1.3	127.	-12.	-114.	7.46	6.24	-3108.	-0.00001
18.0	30.1	-25.6	65.	-41.	0.	7.09	6.72	-3108.	-0.00002
18.0	0.0	-29.1	64.	-35.	0.	6.86	6.63	-3108.	-0.00002
19.0	0.0	-29.0	60.	-31.	0.	6.72	6.57	-3108.	-0.00002
19.0	0.0	-28.8	56.	-28.	0.	6.61	6.51	-3108.	-0.00002
19.0	0.0	-28.7	53.	-25.	0.	6.53	6.46	-3108.	-0.00001
20.0	0.0	-28.6	50.	-22.	0.	6.47	6.41	-3108.	-0.00001
20.0	0.0	-28.5	47.	-19.	0.	6.42	6.37	-3108.	-0.00001
20.0	0.0	-28.5	45.	-17.	0.	6.37	6.33	-3108.	-0.00001
21.0	0.0	-28.4	43.	-15.	0.	6.33	6.29	-3108.	-0.00001
21.0	0.0	-28.3	41.	-13.	0.	6.30	6.26	-3108.	-0.00001
21.0	0.0	-28.2	39.	-12.	0.	6.27	6.23	-3108.	-0.00001
22.0	0.0	-28.2	37.	-10.	0.	6.24	6.21	-3108.	-0.00001
22.0	0.0	-28.1	36.	-9.	0.	6.21	6.19	-3108.	0.00000
22.0	0.0	-28.1	34.	-7.	0.	6.19	6.16	-3108.	0.00000
23.0	0.0	-28.1	33.	-6.	0.	6.17	6.14	-3108.	0.00000
23.0	0.0	-28.0	32.	-5.	0.	6.15	6.13	-3108.	0.00000
23.0	0.0	-28.0	31.	-4.	0.	6.13	6.11	-3108.	0.00000
0.0	0.0	-78.1	80.	-2.	0.	5.51	4.89	-3108.	0.00000
0.0	0.0	-77.0	66.	11.	0.	5.10	4.69	-3108.	0.00000
0.0	0.0	-76.4	60.	17.	0.	4.85	4.59	-3108.	0.00001
1.0	0.0	-76.1	56.	20.	0.	4.69	4.54	-3108.	0.00001
1.0	0.0	-75.9	53.	23.	0.	4.59	4.50	-3108.	0.00001
1.0	0.0	-75.7	50.	25.	0.	4.53	4.46	-3108.	0.00001
2.0	0.0	-75.5	48.	27.	0.	4.48	4.43	-3108.	0.00001
2.0	0.0	-75.3	46.	29.	0.	4.44	4.40	-3108.	0.00001
2.0	0.0	-75.2	45.	30.	0.	4.41	4.38	-3108.	0.00001
3.0	0.0	-75.0	43.	32.	0.	4.38	4.35	-3108.	0.00001
3.0	0.0	-74.9	42.	33.	0.	4.36	4.33	-3108.	0.00001
3.0	0.0	-74.8	40.	34.	0.	4.34	4.32	-3108.	0.00002
4.0	0.0	-74.7	39.	35.	0.	4.32	4.30	-3108.	0.00002
4.0	0.0	-74.6	38.	36.	0.	4.30	4.28	-3108.	0.00002
4.0	0.0	-74.6	37.	37.	0.	4.28	4.27	-3108.	0.00002
5.0	0.0	-74.5	36.	38.	0.	4.27	4.26	-3108.	0.00002
5.0	0.0	-74.4	35.	39.	0.	4.26	4.24	-3108.	0.00002
5.0	22.0	-71.7	34.	38.	0.	4.26	4.26	-3108.	0.00002
6.0	108.2	-21.1	-74.	96.	0.	5.56	6.86	-3108.	0.00004
6.0	162.0	3.7	-58.	54.	0.	6.53	7.51	-3108.	0.00002
6.0	211.5	35.2	-56.	21.	0.	7.28	8.02	-3108.	0.00001
7.0	259.6	71.6	-60.	-11.	0.	7.90	8.53	-3108.	0.00000
7.0	306.2	111.4	-66.	-45.	0.	8.48	9.06	-3108.	-0.00002
7.0	351.5	153.2	-72.	-81.	0.	9.05	9.62	-3108.	-0.00004
8.0	395.3	196.1	-79.	-117.	0.	9.62	10.19	-3108.	-0.00005
8.0	436.9	238.4	-85.	-154.	0.	10.19	10.77	-3108.	-0.00007
8.0	476.3	279.5	-90.	-190.	0.	10.77	11.34	-3108.	-0.00008
9.0	513.3	318.7	-94.	-225.	0.	11.33	11.89	-3108.	-0.00010
9.0	547.1	354.9	-97.	-258.	0.	11.86	12.40	-3108.	-0.00011
9.0	577.8	387.7	-99.	-28[illegible]	0.	12.37	[illegible]	-3108.	[illegible]
10.0	605.1	417.0	-100.	-317.	0.	12.85	13.33	-3108.	-0.00014
10.0	628.4	441.9	-100.	-342.	0.	13.28	13.72	-3108.	-0.00015
10.0	647.9	462.5	-99.	-364.	0.	13.67	14.06	-3108.	-0.00016
11.0	663.3	478.7	-97.	-383.	0.	14.01	14.35	-3108.	-0.00017
11.0	674.3	490.1	-93.	-398.	0.	14.30	14.58	-3108.	-0.00017
11.0	681.0	496.9	-89.	-409.	0.	14.52	14.75	-3108.	-0.00018

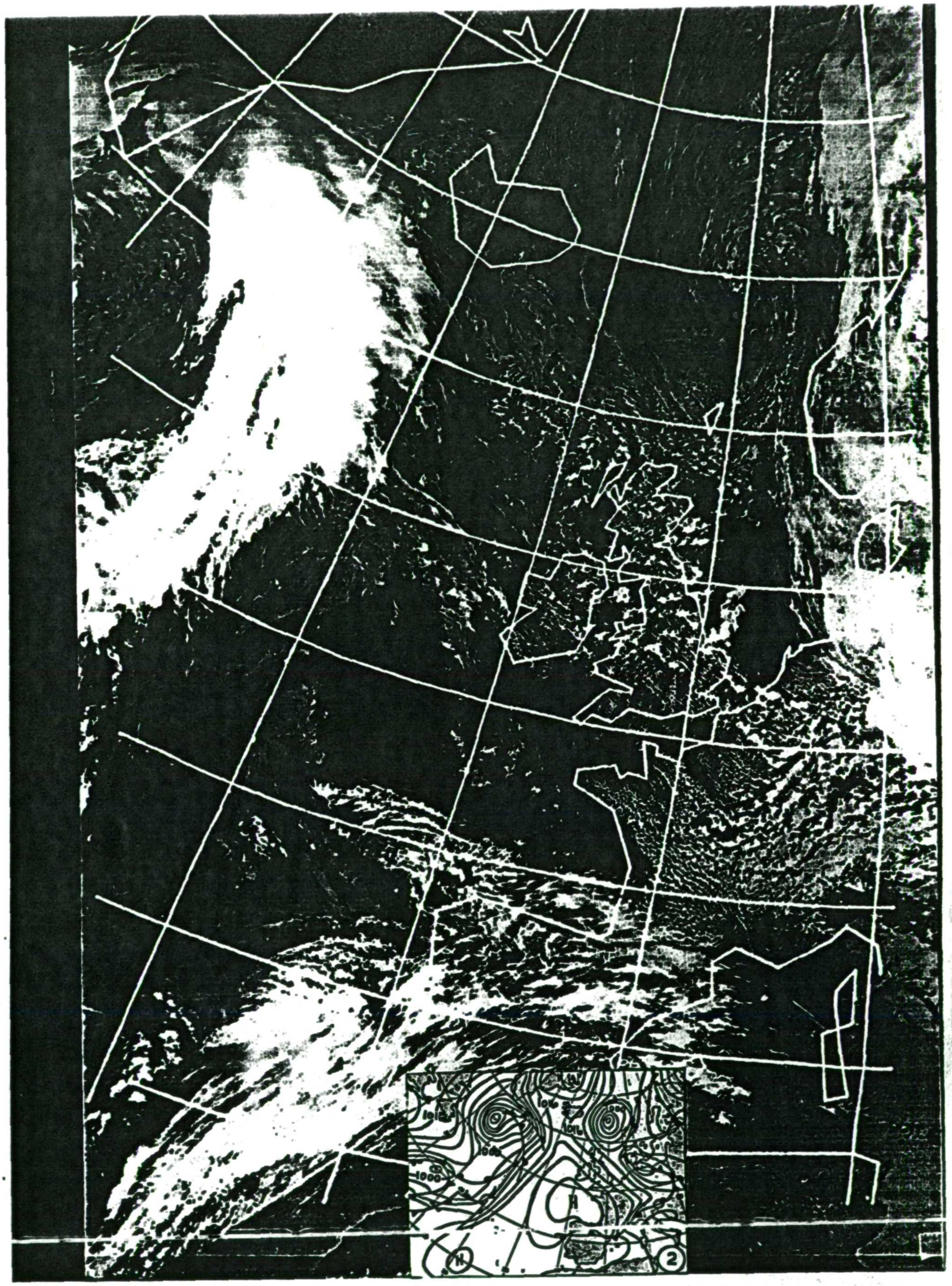
~~TO~~	T36	Air	T18	~~Tslab~~
12.80	9.50	9.20	12.30	13.0
13.00	9.50	9.30	12.40	13.5
13.90	9.60	9.80	12.50	14.0
14.70	9.70	10.40	12.60	15.1
13.60	9.80	10.10	12.50	13.7
12.40	9.80	9.60	12.50	12.8
12.10	9.90	9.50	12.40	12.6
12.20	10.00	9.60	12.20	12.9
12.30	10.10	9.80	11.80	13.2
11.60	9.90	9.50	11.70	12.0
11.20	10.00	9.30	11.60	11.4
11.00	10.00	9.20	11.60	11.3
10.90	10.20	9.20	11.40	11.1
10.70	10.10	9.20	11.30	11.0
10.50	10.20	8.40	11.30	10.4
10.00	10.30	8.00	11.20	9.7
9.40	10.30	6.70	11.00	8.7
8.70	10.20	6.00	10.90	8.4
8.50	10.30	6.50	10.70	8.0
8.20	10.30	6.30	10.50	7.8
8.20	10.20	6.10	10.40	7.4
7.60	10.20	6.10	10.20	7.2
7.20	10.20	5.90	10.00	6.7
6.60	10.10	5.70	9.90	6.1
6.60	10.10	5.70	9.70	5.7
6.00	10.10	5.60	9.50	5.4
5.80	10.00	5.40	9.30	5.2
5.60	10.10	5.70	9.10	4.9
5.40	9.90	5.60	9.00	4.8
5.20	9.90	5.50	8.80	4.7
5.10	9.90	5.60	8.70	4.5
5.00	9.80	5.40	8.40	4.4
4.90	9.70	5.50	8.30	4.3
4.80	9.60	5.50	8.20	4.2
4.60	9.60	5.10	8.00	4.0
4.50	9.50	5.10	8.00	3.8
4.50	9.50	5.10	7.90	3.6
4.40	9.40	5.00	7.70	3.6
4.20	9.40	4.70	7.60	3.5
4.10	9.30	4.40	7.50	3.4
4.00	9.20	4.50	7.40	3.3
3.80	9.10	4.30	7.40	3.2
3.80	9.10	4.20	7.30	3.2
3.70	9.10	4.50	7.20	3.1
3.70	9.00	4.30	7.00	3.0
3.60	9.00	3.90	7.00	2.8
3.50	8.90	4.20	6.90	2.7
3.50	8.80	4.30	6.60	2.7
3.40	8.60	4.00	6.60	2.7
3.50	8.50	4.70	6.40	2.8
3.60	8.50	4.60	6.50	2.8
3.70	8.50	4.60	6.50	2.9
3.80	8.50	4.50	6.40	2.7
3.90	8.40	4.00	6.30	2.7
4.00	8.40	4.70	6.30	2.9
4.40	8.20	5.10	6.20	3.1
5.00	8.20	5.40	6.30	3.6
5.90	8.30	5.90	6.30	4.4
6.90	8.20	6.30	6.40	5.8
7.80	8.10	6.70	6.50	7.1
8.90	8.00	7.30	6.60	8.4
9.90	8.00	7.60	6.80	9.9
11.60	7.90	7.90	7.10	11.2
12.10	7.90	8.70	7.40	12.8
13.40	8.00	9.50	7.70	14.7
14.00	[illegible]	[illegible]	[illegible]	[illegible]
14.60	8.00	9.60	8.50	16.00
15.30	8.00	9.40	8.80	16.90
14.60	8.10	9.80	9.20	15.60
14.90	8.10	10.30	9.50	16.10
16.10	8.10	10.40	9.80	17.00
16.80	8.20	10.40	9.80	17.40

Model Output 01-04-80 **Actuals**





01-02 APRIL 1980



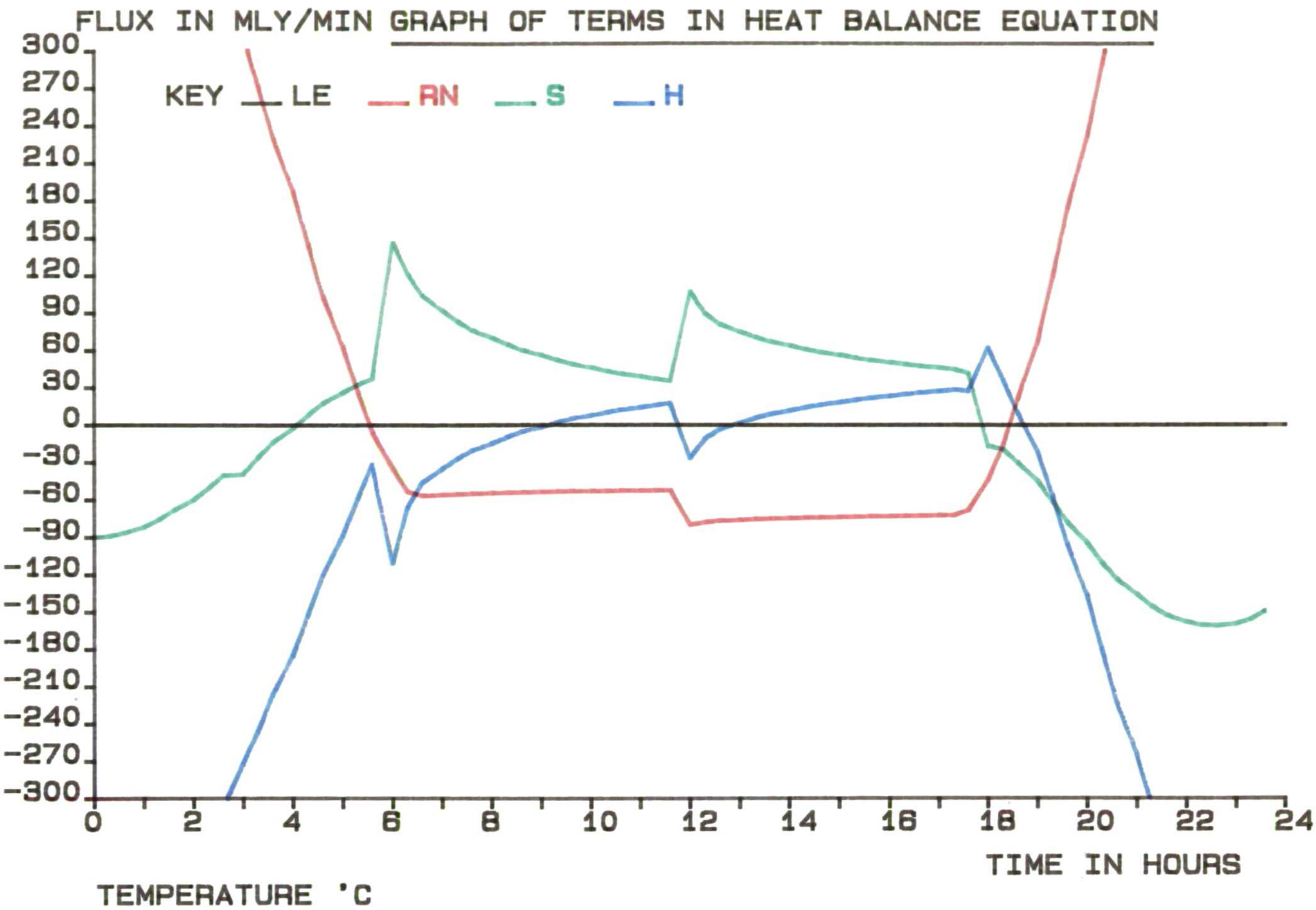
02-04-80

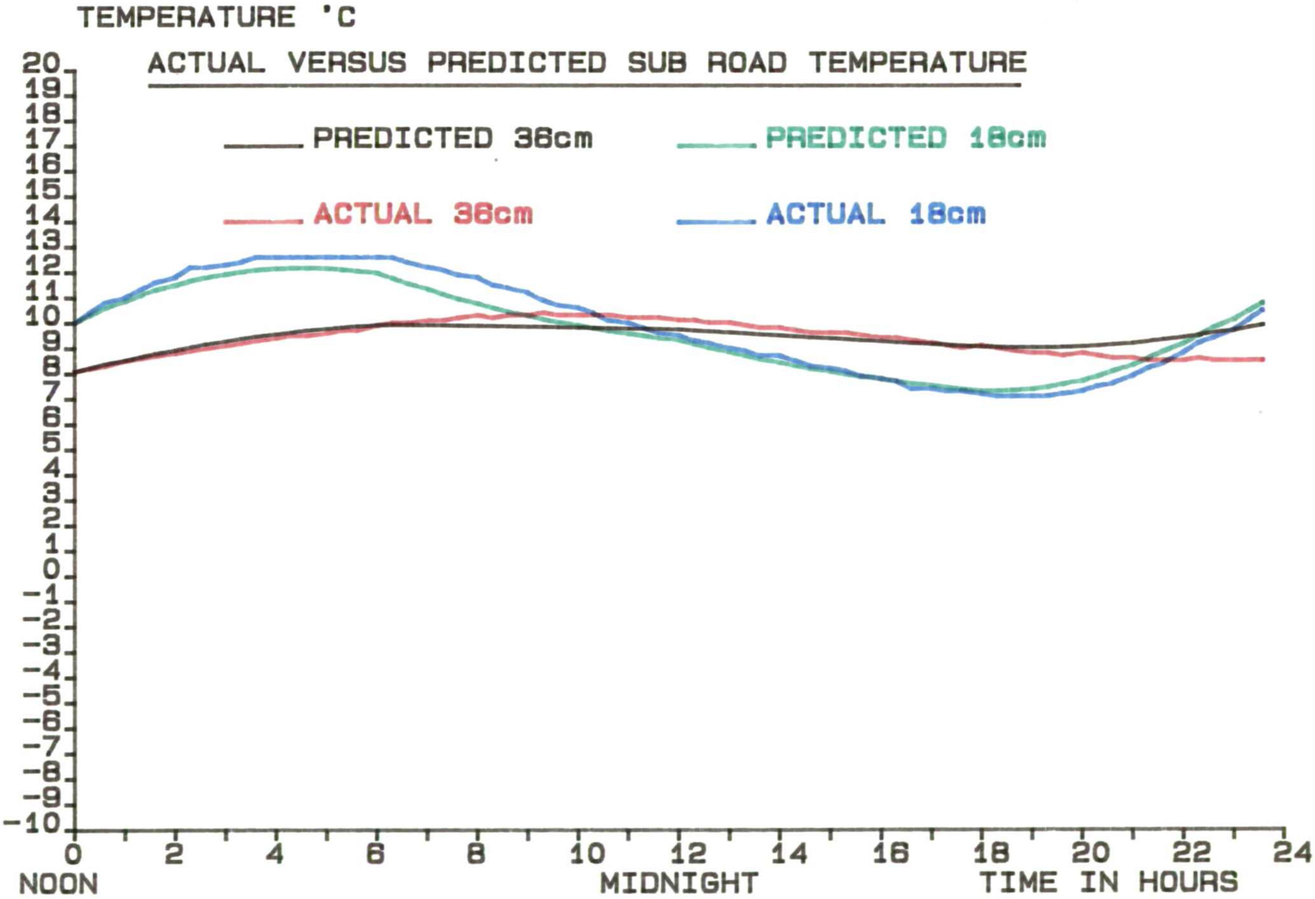
COMPUTED DATA
SAT. VAP. PRESSURE(MB)= 13.29
VAPOUR PRESSURE(MB)= 7.98
REL. HUMIDITY FRACTION = 0.60
APPROX. PRECIP. WATER(MM)= 12.6
ROAD DAMPING DEPTH(CM)= 72.
AIR DAMPING DEPTH(CM)= 3294. 2818.
AIR HEAT TRANSFER COEF.(CGS)= 0.00388 0.00292

DEC	R	T36	T18	TS	UA	D	TIME WET
5.465	1.000	281.3	283.2	17.4	705. 501.	0.5	0

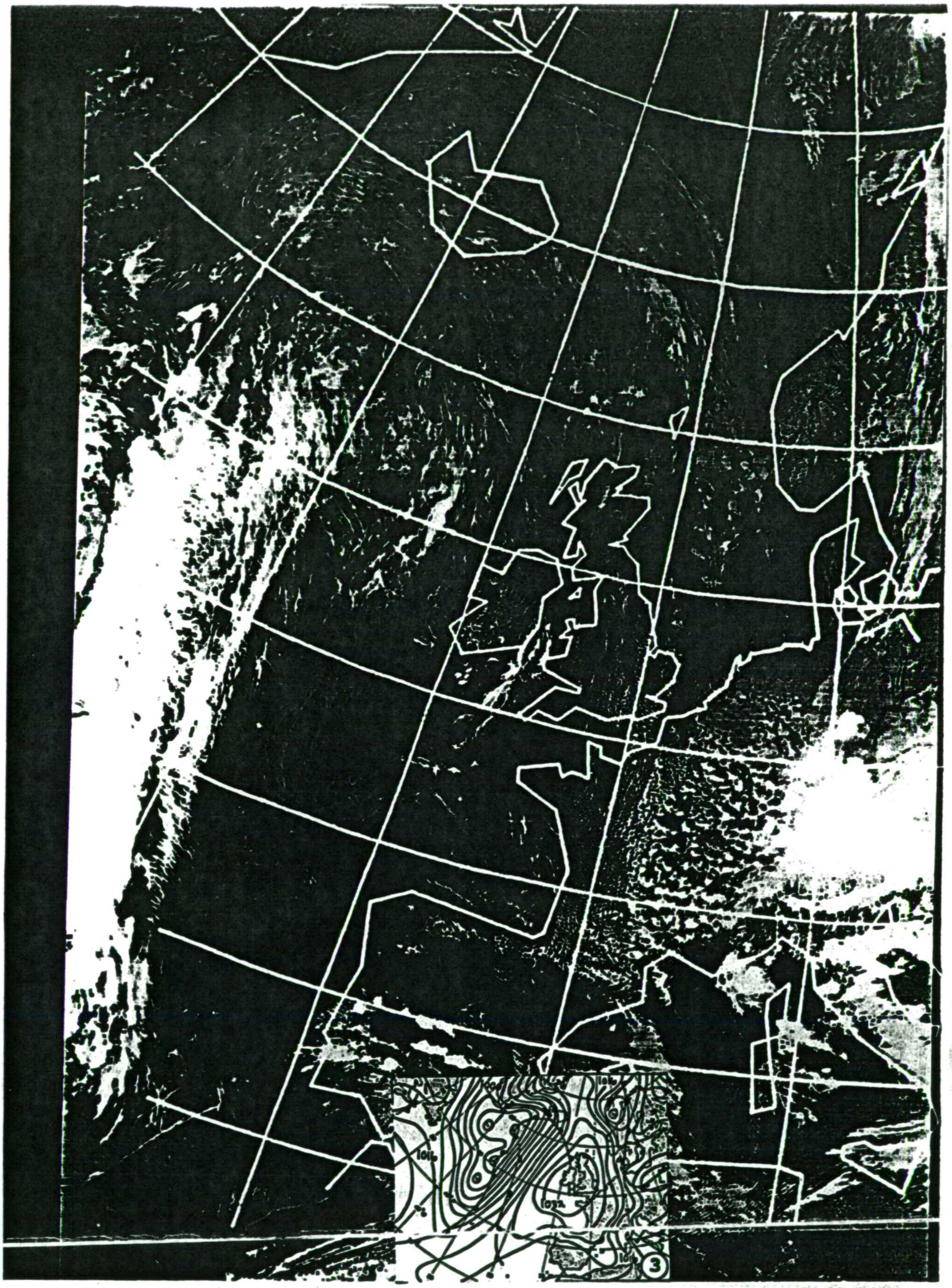
SOLAR TIME	SUN	RN	S (ALL MLY./MIN.)	H	LE	TD	TC (C.)	SUM	RI	TO	T36	Air	T18	Tsla
12.0	685.0	493.3	-90.	-404.	0.	17.40	18.74	1.	-0.00027	17.40	8.10	10.30	10.00	18.5
12.0	682.8	490.9	-89.	-402.	0.	18.06	18.72	0.	-0.00027	16.50	8.20	10.30	10.40	17.4
12.0	676.1	483.8	-86.	-398.	0.	18.35	18.64	0.	-0.00026	16.70	8.30	10.70	10.80	17.7
13.0	665.3	472.1	-82.	-391.	0.	18.43	18.51	0.	-0.00026	19.60	8.50	11.30	11.00	22.3
13.0	649.9	455.7	-76.	-380.	0.	18.38	18.32	0.	-0.00025	19.30	8.60	11.80	11.30	21.7
13.0	630.5	434.7	-69.	-367.	0.	18.23	18.08	0.	-0.00024	19.60	8.70	12.00	11.60	22.5
14.0	607.2	409.6	-60.	-350.	0.	18.01	17.79	0.	-0.00023	17.60	8.80	11.10	11.80	18.7
14.0	580.1	380.2	-51.	-330.	0.	17.72	17.43	0.	-0.00022	17.80	8.90	11.40	12.20	19.4
14.0	549.4	347.0	-40.	-307.	0.	17.37	17.02	0.	-0.00020	17.70	9.00	12.10	12.20	19.3
15.0	519.4	311.5	-40.	-272.	0.	17.08	16.80	0.	-0.00018	17.90	9.10	11.10	12.30	18.9
15.0	482.3	271.9	-26.	-246.	0.	16.71	16.33	0.	-0.00016	16.50	9.20	10.90	12.40	16.9
15.0	442.6	230.4	-14.	-217.	0.	16.26	15.81	0.	-0.00014	16.80	9.30	11.30	12.60	17.1
16.0	400.8	187.8	-3.	-186.	0.	15.76	15.25	0.	-0.00012	16.30	9.40	11.90	12.60	16.6
16.0	356.8	144.9	8.	-153.	0.	15.21	14.67	0.	-0.00010	16.00	9.50	11.80	12.60	16.2
16.0	311.1	102.7	17.	-121.	0.	14.65	14.09	0.	-0.00008	16.10	9.50	12.00	12.60	15.0
17.0	264.2	62.8	26.	-89.	0.	14.09	13.53	0.	-0.00006	15.70	9.60	11.90	12.60	15.2
17.0	215.8	26.1	32.	-59.	0.	13.54	12.99	0.	-0.00004	15.00	9.70	11.80	12.60	14.4
17.0	165.7	-6.0	37.	-32.	0.	13.02	12.50	0.	-0.00002	14.70	9.70	11.50	12.60	14.2
18.0	111.5	-35.2	145.	-111.	0.	11.27	9.52	0.	-0.00008	13.80	9.90	11.20	12.60	12.9
18.0	35.2	-53.6	121.	-67.	0.	10.00	8.73	0.	-0.00005	13.00	10.00	10.50	12.60	12.1
18.0	0.0	-56.9	104.	-47.	0.	9.18	8.37	0.	-0.00003	12.20	10.00	8.50	12.40	11.1
19.0	0.0	-56.1	92.	-35.	0.	8.67	8.16	0.	-0.00002	11.70	10.10	8.30	12.20	10.8
19.0	0.0	-55.5	83.	-27.	0.	8.35	8.02	0.	-0.00002	11.30	10.10	8.20	12.10	10.4
19.0	0.0	-55.0	76.	-21.	0.	8.12	7.90	0.	-0.00001	10.90	10.20	8.20	11.90	10.1
20.0	0.0	-54.6	70.	-15.	0.	7.96	7.80	0.	-0.00001	10.20	10.30	7.40	11.80	9.1
20.0	0.0	-54.3	64.	-10.	0.	7.83	7.71	0.	-0.00001	9.80	10.20	7.30	11.50	8.7
20.0	0.0	-54.0	60.	-6.	0.	7.73	7.63	0.	0.00000	9.10	10.30	6.80	11.40	8.0
21.0	0.0	-53.7	56.	-2.	0.	7.65	7.56	0.	0.00000	8.80	10.30	6.20	11.20	7.5
										8.40	10.40	6.30	10.90	7.1
21.0	0.0	-53.5	52.	2.	0.	7.57	7.50	0.	0.00000	7.90	10.30	5.60	10.70	6.8
21.0	0.0	-53.2	49.	5.	0.	7.51	7.45	0.	0.00000	7.60	10.30	5.60	10.60	6.4
22.0	0.0	-53.1	46.	7.	0.	7.45	7.40	0.	0.00000	7.30	10.30	5.40	10.40	6.1
22.0	0.0	-52.9	43.	10.	0.	7.40	7.35	0.	0.00001	7.20	10.30	5.70	10.10	5.8
22.0	0.0	-52.7	41.	12.	0.	7.36	7.31	0.	0.00001	6.90	10.20	6.00	10.00	5.7
23.0	0.0	-52.6	39.	14.	0.	7.32	7.28	0.	0.00001	6.70	10.20	5.90	9.80	5.6
23.0	0.0	-52.4	37.	16.	0.	7.28	7.25	0.	0.00001	6.60	10.20	5.80	9.60	5.4
23.0	0.0	-52.3	35.	17.	0.	7.25	7.22	0.	0.00001	6.30	10.10	5.80	9.50	5.2
0.0	0.0	-80.1	107.	-27.	0.	6.33	5.41	0.	-0.00005	6.30	10.10	5.40	9.30	5.0
0.0	0.0	-77.9	89.	-11.	0.	5.69	5.05	0.	-0.00002	6.10	10.00	5.40	9.20	4.8
0.0	0.0	-76.9	80.	-3.	0.	5.28	4.86	0.	-0.00001	5.70	10.00	5.60	9.00	4.7
1.0	0.0	-76.2	75.	2.	0.	5.01	4.74	0.	0.00000	5.60	9.90	5.50	8.90	4.6
1.0	0.0	-75.6	70.	5.	0.	4.83	4.65	0.	0.00001	5.40	9.80	5.20	8.70	4.3
1.0	0.0	-75.2	67.	9.	0.	4.71	4.58	0.	0.00002	5.30	9.80	5.20	8.70	4.2
2.0	0.0	-74.8	63.	11.	0.	4.61	4.51	0.	0.00002	5.10	9.70	4.70	8.50	4.0
2.0	0.0	-74.5	61.	14.	0.	4.53	4.45	0.	0.00002	4.90	9.60	4.50	8.30	3.8
2.0	0.0	-74.2	58.	16.	0.	4.46	4.40	0.	0.00003	4.70	9.60	4.10	8.20	3.6
3.0	0.0	-73.9	56.	18.	0.	4.41	4.35	0.	0.00003	4.60	9.60	3.90	8.10	3.5
3.0	0.0	-73.6	54.	20.	0.	4.36	4.31	0.	0.00003	4.40	9.50	4.20	7.90	3.3
3.0	0.0	-73.4	52.	22.	0.	4.31	4.27	0.	0.00004	4.40	9.40	3.80	7.80	3.2
4.0	0.0	-73.2	50.	23.	0.	4.27	4.23	0.	0.00004	4.20	9.40	3.70	7.70	3.0
4.0	0.0	-73.0	48.	25.	0.	4.23	4.20	0.	0.00004	4.20	9.30	3.70	7.40	2.8
4.0	0.0	-72.8	47.	26.	0.	4.20	4.17	0.	0.00005	4.10	9.20	3.40	7.40	2.6
5.0	0.0	-72.7	46.	27.	0.	4.17	4.14	0.	0.00005	4.10	9.10	3.00	7.30	2.5
5.0	0.0	-72.5	44.	28.	0.	4.14	4.11	0.	0.00005	4.30	9.00	3.20	7.30	2.5
5.0	30.1	-68.5	41.	27.	0.	4.14	4.13	0.	0.00005	4.30	9.10	3.30	7.20	2.7
6.0	98.8	-44.0	-17.	61.	0.	4.83	5.52	0.	0.00011	4.60	9.00	3.60	7.10	3.0
6.0	164.6	-16.6	-20.	36.	0.	5.47	6.12	0.	0.00006	5.10	8.90	3.90	7.10	3.5
6.0	232.4	21.1	-31.	10.	0.	6.11	6.76	0.	0.00002	5.70	8.80	4.20	7.10	4.3
7.0	301.3	67.0	-45.	-22.	0.	6.80	7.50	0.	-0.00004	6.70	8.80	5.10	7.10	5.6
7.0	369.7	118.6	-62.	-57.	0.	7.57	8.33	0.	-0.00010					
7.0	437.0	174.0	-78.	-96.	0.	8.41	9.25	0.	-0.00016	7.50	8.70	5.60	7.20	7.0
8.0	502.9	231.6	-95.	-137.	0.	9.32	10.23	0.	-0.00024	8.60	8.80	6.20	7.30	8.6
8.0	565.9	289.1	-111.	-180.	0.	10.28	11.24	0.	-0.00031	9.70	8.70	6.70	7.50	10.4
8.0	625.7	345.4	-124.	-222.	0.	11.26	12.25	0.	-0.00038	10.90	8.60	6.50	7.60	12.1
9.0	682.1	399.4	-136.	-264.	0.	12.25	13.24	0.	-0.00045	11.70	8.60	7.10	7.90	13.4
9.0	733.8	449.5	-146.	-304.	0.	13.22	14.20	0.	-0.00052	13.00	8.50	7.20	8.20	15.1
9.0	780.8	495.0	-153.	-343.	0.	14.16	15.10	0.	-0.00058	14.00	8.50	7.80	8.40	16.5
10.0	822.7	535.6	-158.	-378.	0.	15.04	[illegible]	0.	-0.00064	[illegible]	8.50	7.80	[illegible]	[illegible]
10.0	858.6	570.2	-161.	-410.	0.	15.86	16.68	0.	-0.00070	16.20	8.60	8.30	9.20	19.7
10.0	888.5	598.7	-161.	-438.	0.	16.60	17.34	0.	-0.00074	16.10	8.50	8.50	9.40	19.1
11.0	912.3	621.0	-160.	-462.	0.	17.25	17.91	0.	-0.00078	16.80	8.50	9.10	9.70	20.7
11.0	929.3	636.5	-156.	-481.	0.	17.81	18.37	0.	-0.00081	16.70	8.50	9.00	10.10	19.6
11.0	939.5	645.4	-150.	-496.	0.	18.26	18.72	0.	-0.00084	18.20	8.50	10.20	10.50	21.1

Model Output 02-04-80 Actuals





02-03 APRIL 1980



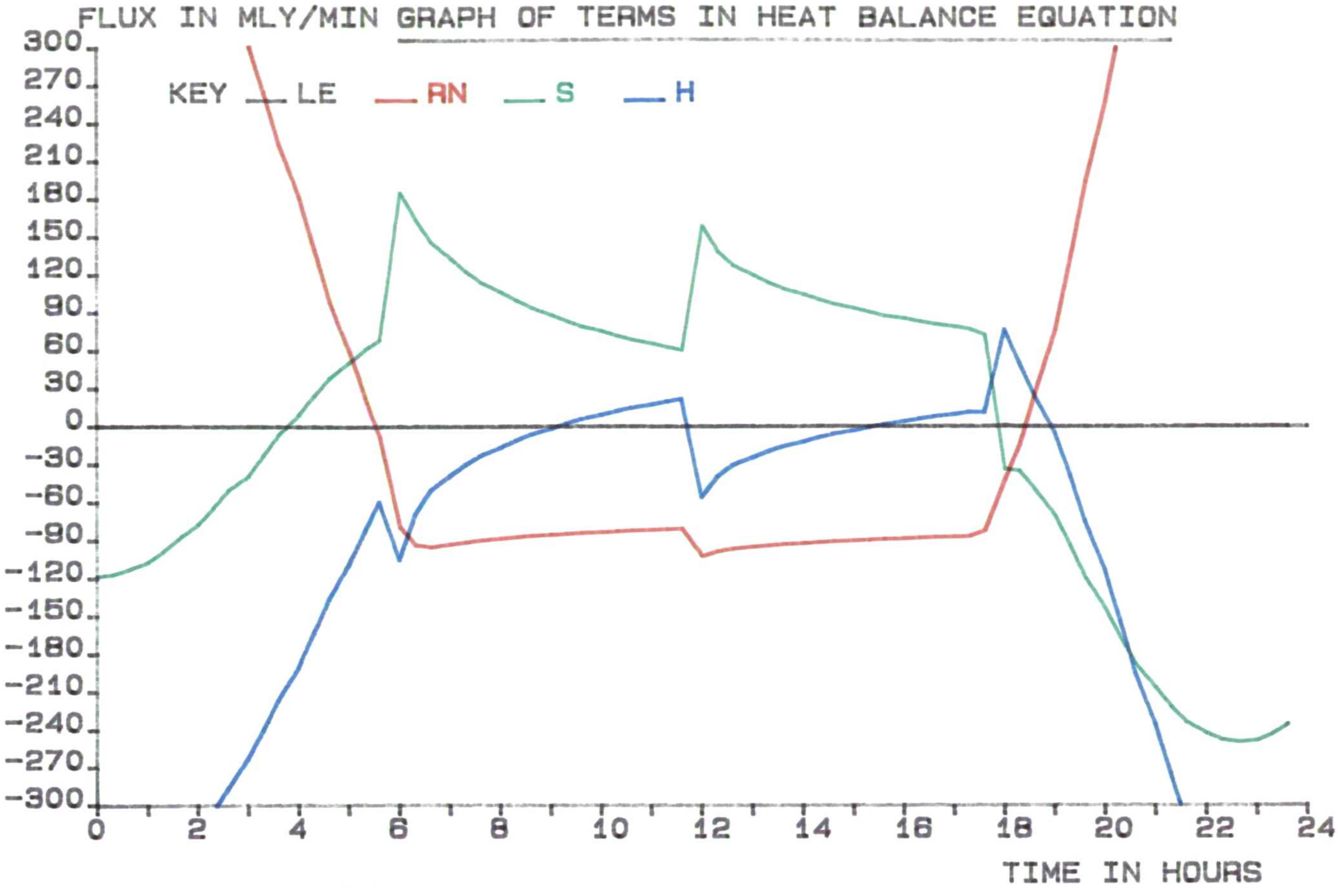
03-04-80

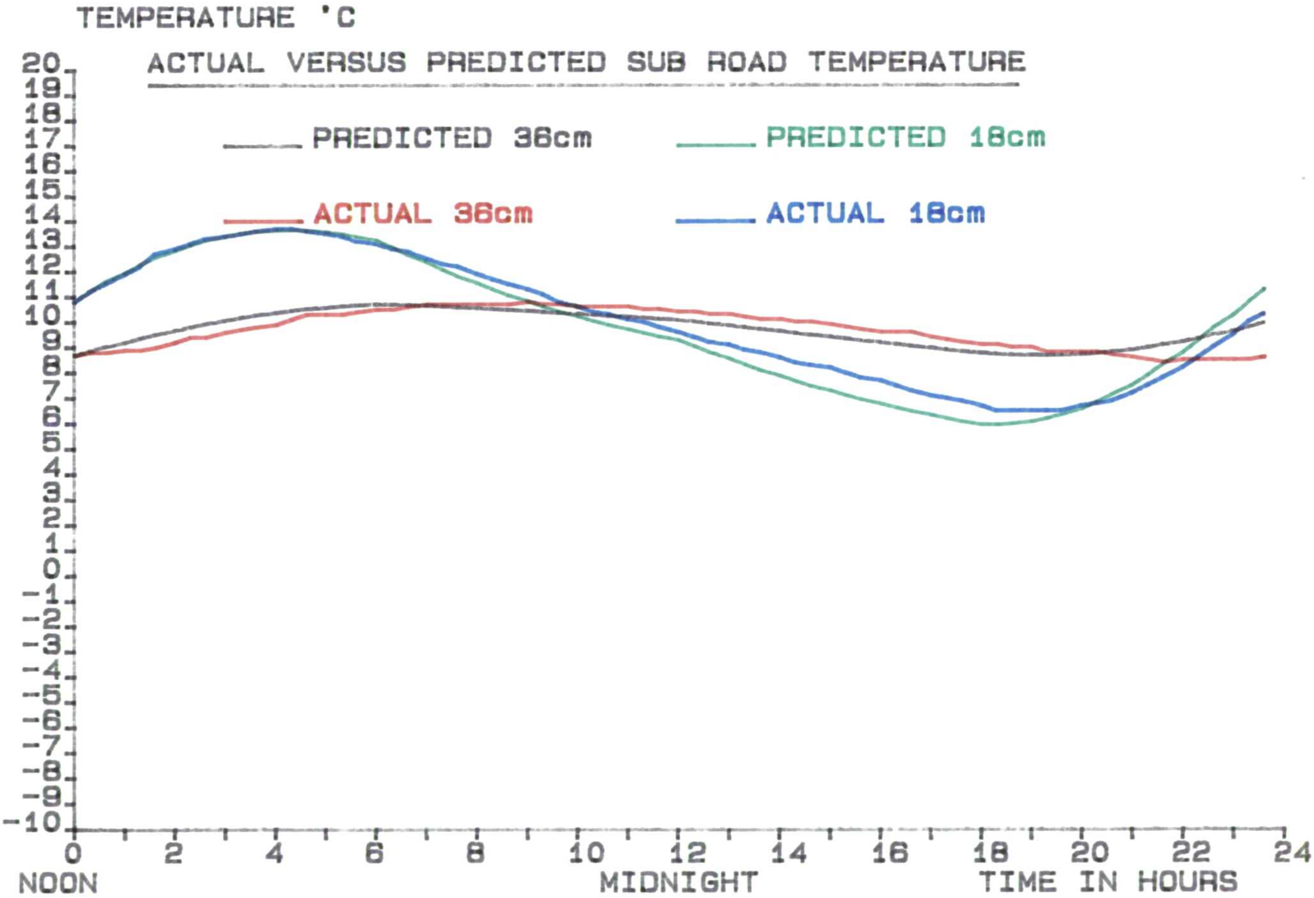
COMPUTED DATA
SAT. VAP. PRESSURE(MB)= 12.86
VAPOUR PRESSURE(MB)= 7.72
REL. HUMIDITY FRACTION = 0.60
APPROX. PRECIP. WATER(MM)= 12.2
ROAD DAMPING DEPTH(CM)= 72.
AIR DAMPING DEPTH(CM)= 2409. 2166.
AIR HEAT TRANSFER COEF.(CGS)= 0.00220 0.00182

DEC	R	T36	T18	TS	UA	D	TIME WET
5.847	1.000	281.9	284.0	19.5	355. 281.	0.5	0

SOLAR TIME	SUN	RN	S	H	LE	TD	TC	SUN	RI	~~TO~~	T36	Air	T18	Tsl
		(ALL MLY./MIN.)					(C.)							
12.0	690.6	480.7	-119.	-362.	0.	19.50	22.29	1.	-0.00155	19.50	8.70	9.90	10.80	23.4
12.0	688.4	478.4	-117.	-361.	0.	20.88	22.25	0.	-0.00154	18.90	8.80	10.20	11.20	22.2
12.0	681.7	471.4	-114.	-358.	0.	21.51	22.15	0.	-0.00153	20.70	8.80	10.90	11.50	24.9
13.0	670.9	459.9	-108.	-352.	0.	21.75	21.98	0.	-0.00151	20.70	8.90	11.30	11.90	25.2
13.0	655.5	443.8	-100.	-344.	0.	21.74	21.73	0.	-0.00147	21.90	8.90	11.40	12.20	26.6
13.0	636.1	423.2	-90.	-334.	0.	21.57	21.40	0.	-0.00143	19.90	9.00	10.50	12.70	23.0
14.0	612.8	398.6	-78.	-321.	0.	21.29	21.00	0.	-0.00137	18.40	9.20	10.20	12.90	20.9
14.0	585.6	369.9	-65.	-305.	0.	20.90	20.51	0.	-0.00131	20.40	9.40	11.00	13.10	23.8
14.0	554.9	337.4	-51.	-287.	0.	20.42	19.95	0.	-0.00123	19.70	9.40	10.70	13.30	22.2
15.0	526.0	302.6	-40.	-263.	0.	19.91	19.40	0.	-0.00113	18.70	9.60	11.30	13.40	21.2
15.0	488.8	263.9	-23.	-241.	0.	19.31	18.71	0.	-0.00104	19.20	9.70	11.40	13.50	21.8
15.0	449.0	223.2	-7.	-217.	0.	18.63	17.95	0.	-0.00093	18.10	9.80	11.20	13.60	20.2
16.0	407.1	181.5	9.	-191.	0.	17.88	17.14	0.	-0.00082	17.20	9.90	11.00	13.70	18.8
16.0	362.9	139.4	24.	-164.	0.	17.09	16.29	0.	-0.00071	16.30	10.10	10.60	13.70	17.5
16.0	317.1	98.0	38.	-137.	0.	16.26	15.44	0.	-0.00059	15.20	10.30	10.50	13.60	16.0
17.0	270.0	58.8	50.	-110.	0.	15.43	14.59	0.	-0.00048	14.70	10.30	10.80	13.50	15.9
17.0	221.4	22.6	61.	-84.	0.	14.60	13.78	0.	-0.00037	14.70	10.30	10.60	13.40	15.3
17.0	171.2	-9.0	68.	-60.	0.	13.82	13.03	0.	-0.00026	14.00	10.40	10.60	13.20	14.8
18.0	107.2	-80.0	185.	-105.	0.	11.74	9.66	0.	-0.00047	13.30	10.50	10.00	13.10	13.8
18.0	34.4	-94.2	163.	-70.	0.	10.14	8.54	0.	-0.00031	12.50	10.50	8.90	12.90	12.7
18.0	0.0	-95.5	146.	-51.	0.	9.05	7.95	0.	-0.00023	11.70	10.60	8.20	12.80	12.0
19.0	0.0	-93.1	132.	-39.	0.	8.31	7.58	0.	-0.00017	11.00	10.70	6.80	12.50	11.0
19.0	0.0	-91.4	122.	-30.	0.	7.81	7.30	0.	-0.00014	10.40	10.70	7.00	12.30	10.4
19.0	0.0	-90.0	113.	-23.	0.	7.44	7.07	0.	-0.00010	10.10	10.70	7.80	12.20	9.9
20.0	0.0	-88.8	106.	-17.	0.	7.16	6.87	0.	-0.00008	9.60	10.70	6.50	11.90	9.3
20.0	0.0	-87.7	99.	-11.	0.	6.93	6.70	0.	-0.00005	9.20	10.70	6.30	11.70	8.8
20.0	0.0	-86.8	93.	-6.	0.	6.74	6.55	0.	-0.00003	8.80	10.70	4.60	11.50	8.4
21.0	0.0	-85.9	88.	-2.	0.	6.57	6.41	0.	-0.00001	8.50	10.80	5.00	11.30	8.0
										8.20	10.70	5.30	11.10	7.7
21.0	0.0	-85.1	83.	2.	0.	6.43	6.28	0.	0.00001	7.80	10.70	5.10	10.80	7.3
21.0	0.0	-84.4	79.	6.	0.	6.30	6.17	0.	0.00002	7.50	10.60	5.60	10.60	7.0
22.0	0.0	-83.8	75.	9.	0.	6.18	6.06	0.	0.00004	7.30	10.60	4.40	10.40	6.6
22.0	0.0	-83.2	71.	12.	0.	6.07	5.97	0.	0.00005	7.00	10.60	4.90	10.30	6.5
22.0	0.0	-82.7	68.	15.	0.	5.98	5.88	0.	0.00006	6.80	10.60	4.60	10.10	6.1
23.0	0.0	-82.2	65.	17.	0.	5.89	5.80	0.	0.00008	6.60	10.50	4.20	10.00	5.9
23.0	0.0	-81.8	62.	19.	0.	5.81	5.73	0.	0.00009	6.30	10.50	3.00	9.80	5.6
23.0	0.0	-81.4	60.	21.	0.	5.74	5.67	0.	0.00010	5.90	10.40	2.90	9.60	5.3
0.0	0.0	-103.0	159.	-56.	0.	4.45	3.16	0.	-0.00048	5.70	10.40	2.60	9.40	5.0
0.0	0.0	-99.1	138.	-40.	0.	3.50	2.54	0.	-0.00034	5.40	10.30	2.40	9.20	4.6
0.0	0.0	-97.0	127.	-31.	0.	2.85	2.20	0.	-0.00027	5.10	10.30	2.10	9.10	4.4
1.0	0.0	-95.6	120.	-25.	0.	2.41	1.96	0.	-0.00021	4.60	10.20	1.00	8.90	4.1
1.0	0.0	-94.4	114.	-20.	0.	2.09	1.78	0.	-0.00017	4.60	10.10	0.90	8.80	3.8
1.0	0.0	-93.5	109.	-16.	0.	1.86	1.63	0.	-0.00014	4.50	10.10	1.60	8.60	3.7
2.0	0.0	-92.7	104.	-12.	0.	1.68	1.49	0.	-0.00011	4.20	10.00	0.00	8.40	3.4
2.0	0.0	-91.9	100.	-9.	0.	1.52	1.37	0.	-0.00008	4.00	10.00	0.50	8.30	3.1
2.0	0.0	-91.2	97.	-6.	0.	1.39	1.26	0.	-0.00005	3.80	9.90	0.60	8.20	3.0
3.0	0.0	-90.6	93.	-4.	0.	1.27	1.15	0.	-0.00003	3.50	9.80	0.60	8.00	2.9
3.0	0.0	-90.0	90.	-1.	0.	1.16	1.06	0.	-0.00001	3.40	9.70	0.50	7.80	2.7
3.0	0.0	-89.5	87.	1.	0.	1.07	0.97	0.	0.00001	3.30	9.60	0.70	7.70	2.6
4.0	0.0	-88.9	85.	4.	0.	0.97	0.88	0.	0.00003	3.10	9.60	-0.60	7.50	2.3
4.0	0.0	-88.4	83.	6.	0.	0.89	0.80	0.	0.00005	2.90	9.60	-0.70	7.30	2.1
4.0	0.0	-88.0	80.	8.	0.	0.81	0.73	0.	0.00007	2.70	9.40	-0.70	7.10	1.8
5.0	0.0	-87.6	78.	9.	0.	0.73	0.66	0.	0.00008	2.70	9.30	0.00	7.00	1.8
5.0	0.0	-87.2	76.	11.	0.	0.67	0.60	0.	0.00009	2.30	9.20	-0.30	6.90	1.8
5.0	31.9	-82.5	72.	11.	0.	0.64	0.61	0.	0.00009	2.50	9.10	-0.20	6.70	1.7
6.0	98.7	-42.3	-34.	76.	1.	1.87	3.10	1.	0.00065	2.70	9.10	-0.70	6.50	1.9
6.0	172.4	-14.6	-36.	50.	0.	2.98	4.10	1.	0.00043	3.30	9.00	0.80	6.50	2.5
6.0	250.4	25.8	-50.	24.	0.	4.04	5.09	1.	0.00020	4.10	9.00	1.40	6.50	3.5
7.0	330.5	76.0	-71.	-5.	0.	5.13	6.21	1.	-0.00004	4.90	8.80	1.90	6.50	4.7
7.0	410.4	132.7	-95.	-38.	0.	6.30	7.47	1.	-0.00032					
7.0	489.3	193.8	-120.	-75.	0.	7.58	8.67	1.	-0.00063	5.90	8.80	2.40	6.50	5.9
8.0	566.6	257.4	-144.	-114.	0.	8.96	10.34	1.	-0.00095	7.20	8.80	3.50	6.70	7.5
8.0	640.6	321.0	-167.	-154.	0.	10.42	11.87	1.	-0.00126	8.30	8.80	4.60	6.80	9.2
8.0	711.0	383.0	-188.	-195.	0.	11.91	13.41	1.	-0.00161	9.60	8.70	5.50	6.90	11.1
9.0	777.3	442.4	-207.	-236.	0.	13.43	14.94	1.	-0.00194	10.90	8.60	6.80	7.20	12.9
9.0	838.3	497.3	-223.	-275.	0.	14.92	16.42	1.	-0.00226	12.30	8.50	7.80	7.50	14.7
9.0	893.6	547.0	-235.	-313.	0.	16.37	17.82	1.	-0.00256	13.60	8.40	8.80	7.80	16.5
10.0	942.9	591.0	-243.	-348.	0.	[illegible]	[illegible]	1.	[illegible]	[illegible]	8.50	9.50	8.20	18.2
10.0	985.3	628.2	-249.	-380.	0.	19.04	20.32	1.	-0.00306	16.10	8.50	9.30	8.60	20.1
10.0	*****	658.5	-250.	-408.	0.	20.21	21.38	1.	-0.00331	17.10	8.50	9.90	9.00	21.5
11.0	*****	682.0	-249.	-433.	0.	21.26	22.31	1.	-0.00350	17.90	8.50	9.80	9.50	22.3
11.0	*****	697.8	-244.	-454.	0.	22.17	23.07	1.	-0.00366	18.60	8.50	11.30	10.00	22.9
11.0	*****	706.2	-236.	-470.	0.	22.92	23.68	1.	-0.00379	18.70	8.60	11.10	10.30	23.4

Model Output 03-04-80 Actuals





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